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The Cumulative Impacts of Management Decisions on Nitrogen Loading to the Rhode Island Salt Ponds

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THE CUMULATIVE IMPACTS OF MANAGEMENT DECISIONS ON NITROGEN LOADING TO THE RHODE ISLAND SALT PONDS

BY

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Abstract

Calculations and measurements of nitrogen in groundwater, stream flow and atmospheric deposition were used to see if the cumulative impacts of management decisions over a fifteen year period of time resulted in measurable changes in nitrogen loading to six of the salt ponds on the south shore of Rhode Island. The changes in the source and transmission of nitrogen were tested by comparing calculated and measured nitrogen data from 1980 and 1995. The calculated method included a nitrogen budget based on land-use and literature values for nitrogen loss to groundwater. The second method compared concentrations of nitrogen in groundwater taken from 111 private homeowner wells in 1980 and 1994. The Paired Student t test was used to test for statistically significant differences. Stream flux from 1980 was compared to data collected in 1994-95 from three streams and the Saugatucket River. Atmospheric deposition of nitrogen is based on 1980 measurements from the University of Rhode Island, Graduate School of Oceanography and Fraher (1991). National averages of nitrogen concentrations in overland runoff were compared to 1980 measurements of runoff in the salt pond region to see if they could be used to estimate nitrogen loading in 1995.

Nitrogen loading increases are evident in the calculated budget, measured groundwater concentrations, stream flux, and atmospheric deposition. Septic systems were the major groundwater source of nitrogen to each of the salt ponds in 1992 and are projected to be a major source when the watersheds are fully developed. Calculations of nitrogen loading at buildout from residential land-use may be underestimated because building variances and grandfathering of substandard lots which are not currently accounted for in the loading budgets. There were no significant differences between the

1980 and 1994 groundwater concentrations of nitrogen. Atmospheric deposition of nitrogen has increased between 1980 and 1990 for wet deposition of nitrogen. A comparison of different methods of calculating or measuring over-land runoff indicates that national concentrations are considerably higher than measured concentrations in southern Rhode Island.

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"A string of shallow salt ponds...." (Lee, 1980)

The Salt Pond Region (SPR) extends across 95 km^2 on the south shore of Rhode Island (See Figure 1). The SPR includes nine shallow lagoons locally referred to as "salt ponds." Evidence of the earliest human activity along the salt pond shores is an Indian fishing camp on the west side of Potter Pond which probably existed between 1000 and 500 B.P. (Lee, 1980). Since, the Ponds have been an integral part of local life, providing resources for European trade, early colonial farmers, mills, recreation, fishing and, in the last forty years, housing development (Lee, 1980).

The most dramatic change in land-use was the loss of farmland and open space. Farmland began to be sold off and developed as small residential parcels before World War II, on Great Island in Point Judith Pond, and Fort Neck Cove on Ninigret Pond (Lee, 1980). Today in the SPR, large parcels of land are rare, and the open coastal plain scenery is being replaced with single family residences. The summer cottages and bungalows are being renovated to allow year-round use. According to U.S. Census Bureau data (1970 and 1990), the number of SPR houses classified as seasonal use declined between 1970 and 1990. Seasonal housing declined from 49% to 30% in Charlestown, from 29% to 20% in South Kingstown, and from 42% to 23% in Narragansett.

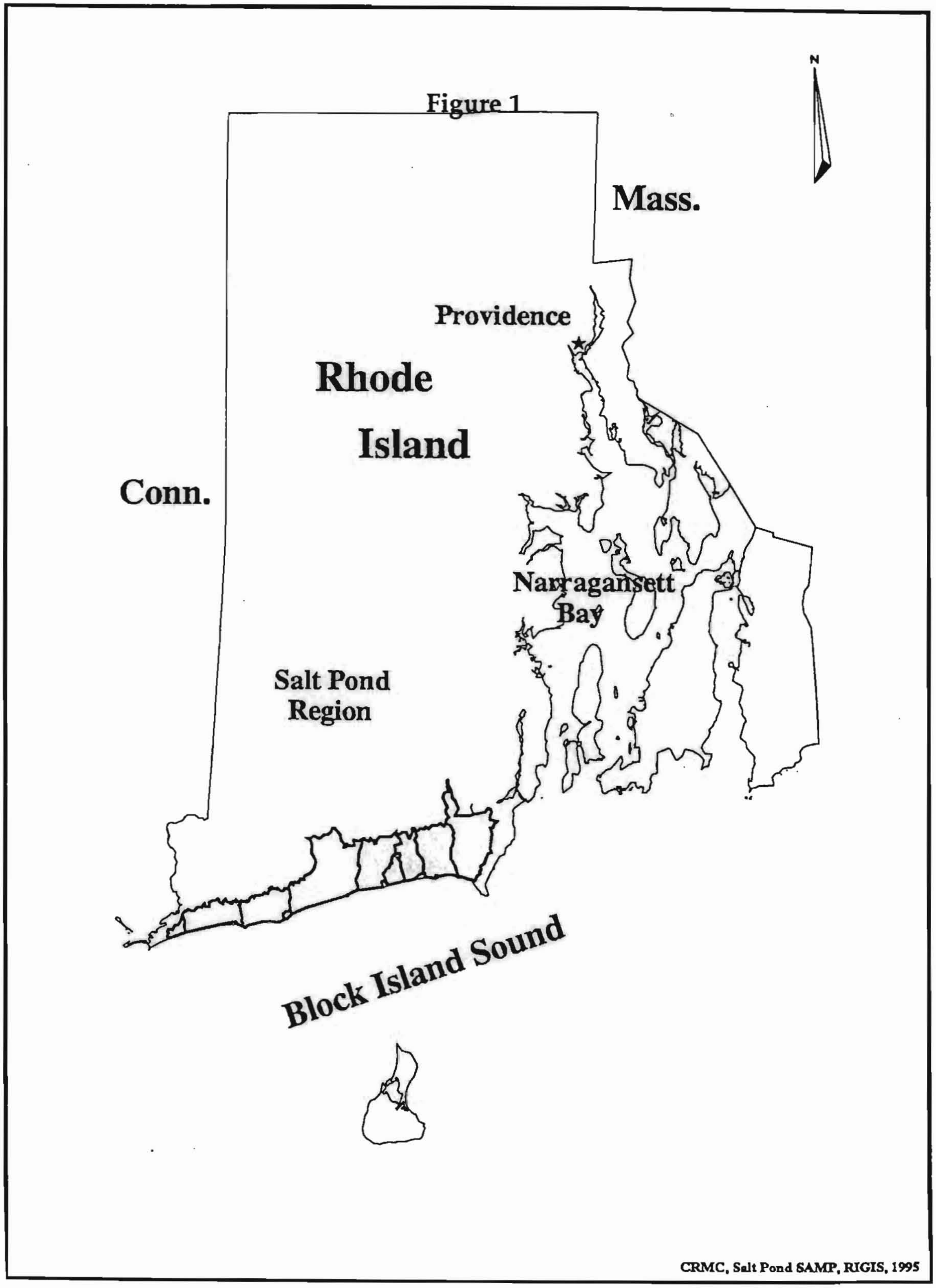
Figure 1
N
Mass.
Providence
Rhode
Island
Conn.
Narragansett
Bay
Salt Pond
Region
Block Island Sound
CRMC, Salt Pond SAMP, RIGIS, 1995

Changes in housing use parallel the influx of population to coastal counties in the last twenty years (Morris, 1990). Perhaps the greatest challenge resulting from the coastal population explosion in the SPR is the need for communities to balance economic gain with the health of their water resources.

The Nitrogen Loading Problem
"Nutrients and Coastal Waters - Too Much of a Good Thing?"(Nixon, 1993)

In 1968, Garret Hardin wrote that pollution problems in general are a consequence of population. In the case of nitrogen, this is particularly true. Increases in population affect the quantity and fate of nitrogen in the environment. This relationship exists, in part, because growing populations demand increasing amounts of nitrogen fertilizer to meet basic human nutritional needs (Nixon, 1993). An expanding population also requires more housing and development in cities, towns and rural areas. Along with new houses there are sewers, sewage treatment systems, and individual sewage disposal systems (ISDS) which introduce additional amounts of nitrogen into the environment. There are also more cars emitting nitrogen oxides into the atmosphere, which leads to higher concentrations of nitrogen in atmospheric deposition. Depending on income, the habits and preferences of humanity also change with an expanding population. In developed countries there is the possibility for more domestic animals, fertilized lawns, horses, cows, playing fields, and golf ranges which are all sources of nitrogen. Where there are large population centers, there is an infrastructure of highways, roads, and services, which results in an increase of impervious surfaces and a corresponding increase in overland run-off. These changes in the landscape influence the transmission of nitrogen to watershed drainage basins. Increases of nitrogen in the form of nitrate can be a problem for private homeowner wells and public water supplies if they exceed the ten parts per million health limit (U.S. Environmental Protection Agency, 1976). High nitrate-nitrogen levels in drinking water can cause methemolobinemia (a potentially lethal decreased ability of the blood to transport oxygen) in infants, and have been correlated with malformations (National Research Council, 1977; Dorsch et al., 1984). In coastal areas, the potential to load nutrients from an entire watershed into coastal and estuarine waters poses multiple problems for human, natural, and economic health.

The Nitrogen Loading Problem for Coastal Water Quality

Although nutrients are important for the productivity of coastal marine ecosystems, excessive amounts of anthropogenic inorganic nitrogen can produce undesirable changes in these systems (Ryther and Dunstan, 1971). The real problem for scientists and managers is that nobody knows exactly how much nitrogen is too much in these systems. Nitrate-nitrogen loading into coastal embayments from overland runoff, precipitation, groundwater, streams and offshore is consumed by phytoplankton and macroalgae. Green and red benthic macroalgae are found in the salt ponds attached to rocks, shells and animal carapaces, with the largest component unattached and free floating (Harlin and Sheath, 1988). Phytoplankton are suspended in the water column and are primarily in the form of centric and chained diatoms, dinoflagellates and picoplankton (Smayda, 1971). Anthropogenic introduction of nitrate into the salt ponds increases the productivity of these marine plant communities. As these species proliferate, mass algal growth blocks sunlight from other plant species like eel grass, <u>*Zostera marina*</u> ,and bottom organisms. Increasing nutrient loading leads to the replacement of seagrasses and slow-growing macroalgae by fast-growing macroalgae and phytoplankton (Duarte, 1995). Managers need to understand how these changes disrupt the food chain and the implications for marine species. If managers can associate various quantities of nitrogen loading and the impacts on coastal habitats, then land-use can be managed to limit the source and transmission of nitrogen in coastal watersheds.

Consider the nonpoint source pollution problem of individual sewage disposal systems (ISDS). These systems can typically achieve an average of only 20% nitrogen removal during the infiltration and percolation of septic tank effluent (Siegrist and Jenssen, 1990). In densely developed areas which use ISDS as the sole form of sewage removal, nitrogen loading to groundwater is a problem for public drinking water supplies. When these areas are adjacent to coastal embayments fed by groundwater springs and streams, the cumulative effect of many ISDS can be a problem for coastal water quality, which in turn impacts aquatic vegetation, fish and shellfish habitat, and the marine food chain. The cumulative impacts of development on water quality and the coastal lagoon ecosystem are difficult to measure because there are no immediate signs of pollution or habitat degradation. Although nuisance algal blooms are noticeable symptoms of declining water quality, they are hardly the evidence necessary to prohibit the installation of additional conventional septic systems. Instead, scientists and managers alike must document land-use changes in the watershed to demonstrate that increases in development, dependent upon ISDS, result in changes in the amount of nitrogen loading into a particular embayment. Quantifying changes in nitrogen loading over a period of time and associating these changes with various land-uses will give town planners and coastal managers the documentation they need to develop sustainable land-use practices which limit population and development in sensitive watershed areas. Measuring the cumulative impacts of management decisions on nitrogen loading is particularly important for coastal water quality because of the potential threat of increased development from a growing world population (World Resources Institute, 1994), and a national trend to live in the coastal zone (Culliton et al., 1992).

The Coastal Lagoon Ecosystem

Bar-built estuaries are one of four classes of estuaries and are more commonly referred to as coastal lagoons. Coastal lagoons are shallow estuaries separated from the open ocean by bars composed of sand deposited parallel to the coast by wave action (Thurman, 1993). Coastal lagoons are situated behind these bars and may or may not have an opening to the sea. All of the salt ponds in this study were temporarily connected with the offshore waters of Block Island Sound by narrow, winding channels that were often blocked by beach sand transported by waves along the shore (Lee, 1980). Between 1910 and 1960, Point Judith, Potter, Ninigret, and Green Hill Ponds were permanently breached (Lee, 1980). In the case of Green Hill and Potter Ponds, the permanent breachways were made for Green Hill through Ninigret Pond, and for Potter through Point Judith Pond. In 1984, the Special Area Management Plan (SAMP) for the salt ponds noted that "the permanent alteration of the breachways that connect the salt ponds to the ocean and one pond to another have brought greater changes to the ecology of the Ponds than any other human activity" (Olsen and Lee, 1984). Table 1 gives a summary of some of the other physical characteristics of the salt ponds and their surface watersheds.

Table 1. Salt pond characteristics (Lee, 1980).

Salt Pond	Area (km^2)	Perimeter (m)	Max. Length (m)	Max. Width (m)	Av. Salinity ($^0/_{00}$)	Av. Depth (m)
Point Judith	6.2	33,200	5,500	2,000	30	1.8
Potter	1.3	15,600	1,100	1,200	28	0.6
Cards	.17	3,970	1,100	900	10	0.4
Trustom	.65	7,000	1,200	800	4	0.4
Green Hill	1.7	13,300	1,900	1,800	24	0.8
Ninigret	6.9	35,100	5,800	2,300	28	1.2

Soils

The salt ponds are underlain by Pleistocene-age glacio-fluvial gravel or ground moraine till (Boothroyd, Friedrich and McGinn, 1985). These types of soils have subsurface horizons composed of well drained permeable sands and gravels. These soil characteristics allow rapid infiltration of septic leachate into underlying groundwater and exacerbate the nitrate-nitrogen and bacterial contamination problems in the SPR (Boyd, 1993).

Groundwater

Since groundwater is the predominant source of freshwater to the salt ponds (Olsen and Lee, 1985), it is also the most accessible route for nutrient transportation. Grace and Kelley (1981) estimated the volume of groundwater input to the salt ponds using groundwater levels measured in test wells and Darcy's Law.[1] There have been attempts to measure groundwater seepage into the Ponds by measuring salinity. These measurements of salinity show that groundwater is percolating up through the bottom of many areas of the Ponds (Nixon et al., 1982). Since interpretation of salinity measurements for rate of input are complicated, "seepage" chambers placed over the bottom of the Ponds have also been used to collect inflowing groundwater from some

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[1]Darcy's Law describes the relationship of groundwater as it moves in response to differences in head and is retarded by its own viscosity (resistance to deformation) as it flows through the aquifer (Dunne and Leopold, 1978). Darcy's Law is represented as follows:

$$Q = Au = wdK\left(\frac{\Delta h}{\Delta l}\right)$$

Where Q = the rate of flow (m^3/day)
A = cross-sectional area of flow (m^2)
u = mean flow velocity (m/day)
w = width of flow (m)
d = depth of flow (m)
K = coefficient of permeability (m/day), also called hydraulic conductivity
Δh = difference in head (m)
Δl = distance between measurement points in the direction of flow (m).

areas. This method revealed that groundwater inflow is patchy and hard to relate to the entire area of the pond (Nixon et al., 1982).

Streams

Small streams flow into most of the salt ponds, except for Point Judith Pond, which receives the Saugatucket River at its northern end. Stream flow into the salt ponds was measured only for Ninigret, Green Hill, Cards and Point Judith Ponds (Nixon et al., 1982; Ernst et al., in prep.). The importance of stream flow into the salt ponds lies in the possibility for nutrient and bacterial transportation from upper portions of the watershed. In 1995, the Salt pond Watchers, a volunteer monitoring group, began a monitoring effort specifically for bacteria along the streams. This effort was in response to higher levels of bacteria, found in the Saugatucket River in the summer of 1994.

Nitrogen Loading to the Salt ponds

Over the last thirty to forty years, marine scientists became aware of the importance of studying the impacts of nitrogen on marine ecosystems (Nixon, 1993). Today, researchers have established nitrogen as the nutrient limiting primary production in most temperate coastal waters (Ryther and Dunstan, 1971; Vitousek and Howarth, 1991). The problem of eutrophication from excessive nitrogen loading became a concern in the Long Island bays during the 1950s. Development of the Long Island duckling industry resulted in the organic pollution of Great South Bay and Moriches Bay. Subsequently, dense algal blooms developed and impaired the shellfish resources of the bays (Ryther and Dunstan, 1971). Interest in eutrophication grew over the years as nutrient problems were discovered in coastal embayments, including Tampa

Bay (Johansson and Lewis, 1992), Chesapeake Bay (Orth and Moore, 1983), Delaware Bay (Dove and Nyman, 1995), San Francisco Bay, Buzzards Bay (Valiela et al., 1993) and others.

In the SPR, the source of nutrient loading is primarily residential land-use. Sources of nitrogen are related to human activity and include lawn fertilizer, ISDS, and domestic pets. In a single family residence in Charlestown, for instance, ISDSs are the largest contributor of nitrate-nitrogen to groundwater (Figure 2). Residents of the salt ponds comment about the nuisance algal blooms and smells of hydrogen sulfide, which are the most noticeable symptoms of declining water quality. However, the sources responsible for pollution of the salt ponds are not easily explained. The situation is reminiscent of Garret Hardin's *Tragedy of the Commons*, except in reverse (Hardin, 1968). The "tragedy" of the commons occurred when members of the community all utilized the commons for their cattle, the result being that none could use the resource because it was depleted. The community had taken from the common resource, to its detriment. In the salt pond watersheds, rather than taking from the commons, the population of the salt pond watersheds are contributing nitrogen into the salt ponds (the common resource), to their detriment.

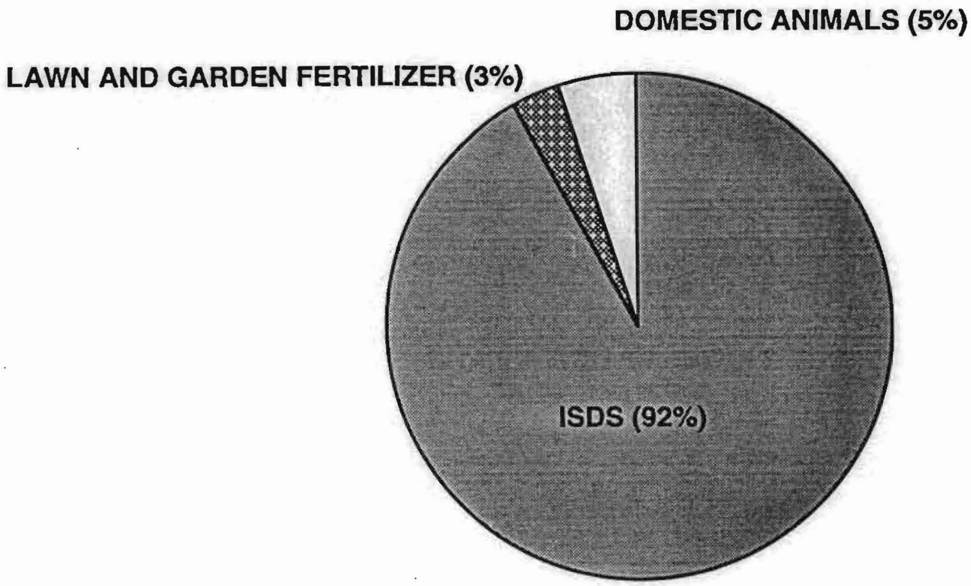

Figure 2. Estimated sources of nitrate-nitrogen to groundwater from residential development. Based on loadings for ISDS and lawn fertilizer from Gold et al., 1990, and for domestic pet loading in the Long Island 208 Plan, 1978. This figure shows the nitrate-nitrogen input from a household with 2.3 people (1990 U.S. Census Bureau data for Charlestown) on a $1394m^2$ lot (1/3 acre) with $464.7m^2$ of lawn and garden (Cape Cod Commission, 1992).

Nitrogen Loading Problem in the Salt pond Region Recognized

Interest in the changes occurring in the salt ponds, as a result of the developing seasonal population, began in the early 1980's. The State of Rhode Island and local coastal managers alike were concerned about the more than triple increase in development from 1775 units in 1950, to 5570 units in 1980, in six of the salt pond watersheds in the region. Members of the scientific and local communities proposed a management plan to address a potential increase of three times more houses and seven times more people in the SPR by the year 2000 (Olsen and Lee, 1984). The importance of the salt ponds as a coastal and economic resource resulted in research, and eventually management initiatives for the SPR. Between 1980 and 1984, the State of Rhode Island Coastal Resources Management Council (RICRMC) adopted a Special Area Management Plan (SAMP) based upon research completed at the University of Rhode Island Graduate School of Oceanography, and the Coastal Resources Center (URI/GSO/CRC). The Salt Pond SAMP water quality goal was to slow the increase in the amount of nitrogen loading to the salt ponds by decreasing the density of future development in the watershed. The RICRMC identified those areas in the watersheds which were most sensitive to development, and recommended zoning changes to the four town governments with jurisdiction in the SPR. The RICRMC based these recommendations on the premise that lower density development would mean less transfer of nitrogen from residential land-use to groundwater flowing into the salt ponds. Four of the five local municipalities in the SPR did respond to these recommendations by agreeing to change the zoning requirement for residential development to two acres for all unplatted lots of land. The Town of Westerly decided not to change the zoning for large lots and the result has been a significant increase in the density of development in the salt ponds located in the Town of Westerly (Maschaug Pond, Winnapaug Pond and Quonochontaug Pond). The towns also have worked through other ordinances to conserve lands for public access through conservation commissions and land trusts.

State Agency Management in the Salt pond Region

The June 1995 Coast Alliance report on the "State of the Coasts" noted, that in Rhode Island development is, and can be, accommodated because of the flexibility of the state coastal zone management plan. The Coast Alliance report also notes that coastal regulations have not prohibited development in Rhode Island's coastal zone (Holing, et al., 1995). Development is prohibited on undeveloped barrier beaches (R.I. Coastal Resources Management Plan, 1990). However, if a development proposal meets the local zoning regulations and RICRMC density requirement, then development may proceed. Many of these houses were built on lots which were zoned prior to the adoption of the SAMP in 1984 (James R. Boyd, personal communication, 1996). Today, increasing development on the small one-quarter - one-half acre lots zoned prior to 1984, and development on the two acre lots zoned after 1984 provide the potential for an increase in year round housing.

One of the resource management problems confronting the SPR is that coastal land-use planning by state and local agencies does not relate development directly to water quality. For instance, although the State of Rhode Island Department of Environmental Management (RIDEM) recently amended regulations permitting the use of denitrification units as appropriate means of sewage treatment, these regulations did not require the use of denitrification systems in high density development, or situations where nitrogen from septic systems were a threat to salt pond water quality

(RIDEM, 1995). Instead, RIDEM relies on the RICRMC SAMP regulations to require denitrification installation over the traditional ISDS.

There are several institutional reasons for these problems. Land-use in the salt pond watersheds is managed by the individual town in which the salt ponds are located geographically. The towns look to guidance from the state to regulate sources of pollution and to monitor water quality in the salt ponds. The two state agencies, the RIDEM and the RICRMC, have different jurisdictions and mandates for water quality in the region. The water quality management framework between the towns and two agencies is not integrated by regulations, mandates or common objectives.

The RICRMC is the primary agency charged with the protection and management of the SPR. The SAMP written for the salt ponds was in response to the water quality problems associated with land-use activities. RICRMC jurisdiction is limited to activities in areas extending only 200 feet from a coastal feature and in the following situations within the salt pond watersheds (R.I. Coastal Resources Management Plan, Section 325, as amended, 1995):

- Subdivisions, cooperatives, and other multi-ownership facilities [of six (6) units or more];
- A structure serviced by an on on-site sewage disposal system serving 2,000 gallons or more per day;
- An activity which results in the creation of 40,000 square feet or more of impervious surface;
- Construction or extension of municipal or industrial sewage treatment facilities and sewer lines;

- Construction or extension of water distribution systems and/or supply lines.

Residential development which does not fall under RICRMC jurisdiction, but is within the SAMP regulatory boundary, does not come under RICRMC purview. This inconsistency exists because RIDEM is the permitting authority for ISDS and is not mandated to consult with RICRMC on development which occurs within the SAMP boundaries.

The RICRMC manages nitrogen sources in the salt pond watersheds through zoning recommendations to the local authorities. Local municipalities are responsible for determining zoning changes and can allow exceptions to the regulations through a zoning variance. Presently, the RICRMC is revising the SAMP to reflect changes in the nutrient loading budget over the last fifteen years, and to incorporate consideration of cumulative impacts within individual pond watersheds and the region as a whole. In addition, RICRMC is working with RIDEM to coordinate permitting of ISDS within the salt pond watersheds.

The R.I. Department of Environmental Management, Division of Water Resources, is also responsible for water quality in the SPR. This division has several sections that are part of the state's water quality management process. These include the Shellfish Monitoring Section, which measures bacteria in the ponds to determine if water levels are safe for shellfish harvesting, and the ISDS Section, which is responsible for the regulation and approval of ISDS. The Department of Environmental Management is currently updating their ISDS regulations which will allow the use of denitrification systems,[2] and will improve the guidelines for siting an ISDS.

Three problems emerge from the management of water quality in the salt ponds. First, RICRMC manages for the impacts of nutrients and bacteria in the salt ponds, but only has jurisdiction over the salt ponds themselves and large-scale projects within the watersheds. Second, in permitting ISDSs, RIDEM does not link water quality standards to ISDS design and location in the watershed. Finally, there is a lack of consistency in the standards and measurements used to manage water quality in the region.

The RIDEM regulations are based on hydrological performance standards for ISDS, and minimization of impacts on-site, without consideration for impacts on the salt pond receiving waters. Rhode Island Department of Environmental Management standards for water quality "define the water quality goals of the water body by designating the use or uses to be made of the water and by setting criteria necessary to protect the uses" (RIDEM 1988). Although nutrients are considered under section 6.31 of the RIDEM water quality regulations as one of the general criteria for which "levels are not to exceed the site-specific limits necessary to control accelerated or cultural eutrophication," there are no guidelines or criteria for what these levels are, nor how they are to be controlled (i.e., through land-use controls, Best Management Practices, or other management tools) (RIDEM 1988).

The RICRMC recently initiated three new policies which are aimed at nutrient reduction for sensitive coastal waters. The establishment of Coastal Buffer Zones was based on the RICRMC's legislative mandate to preserve, protect and, where possible, restore ecological systems (RICRMP, 1996).

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[2]Denitrification systems are an innovative nitrogen reduction technology for on-site sewage treatment. Denitrification systems rely upon a biological process to transform NO_3 to NO_2 to $N_2O + N_2$

Rhode Island's Coastal Nonpoint Pollution Control Program is now being considered for amendment to the RICRMP. Finally, RICRMC requires denitrification systems in some of the critical areas around the salt ponds.

The R.I. Coastal Zone Buffer Program was amended in March of 1994 to the RICRMP. Vegetated buffer zones along the perimeter of the salt ponds can be effective in trapping sediments, pollutants and absorbing nutrients from surface water runoff and groundwater flow (RICRMP, 1996). Based on data from Desbonnet et al., 1994, nitrate removal is variable, but generally low. Up to fifty percent of the nitrate present will be removed in buffers of one hundred meters in width (Desbonnet et al., 1994). RICRMC regulations require one-hundred feet of buffer for development on 1 - $1\frac{1}{2}$ acres of land (RICRMC, 1996). This means that areas around the salt ponds which are developed or plotted for up to one acre will achieve considerably less than fifty percent nitrate-nitrogen reduction.

The Rhode Island Coastal Nonpoint Pollution Control Program is an interagency partnership which addresses nutrient control by five different measures, including a requirement for installation of ISDS that reduce total nitrogen loadings by fifty percent where nitrogen limited surface waters may be adversely affected by groundwater nitrogen loadings (RIDEM et al., 1995).

The Rhode Island vegetated buffer program and Coastal Nonpoint Pollution Control Program are implemented on a case-by case basis (Desbonnet et al., 1994). Although RICRMC regulations specify that greater buffer widths shall be applied along the coastline abutting Type 1 and Type 2 waters[3], most of the areas abutting the salt ponds are already plotted for 1/4 to 1 acre, and could be eligible for a special exception or variance under RICRMC

[3]Type 1 waters are conservation areas and Type 2 waters are low-intensity use. Most of the salt ponds are either Type 1 or 2. For a more through explanation see RICRMC Coastal Resources Management Plan, as amended.

regulations. A variance is granted to an applicant only if the Council finds that the following five criteria are met (RICRMC, 1996):

- The proposed alteration conforms with applicable goals and policies in Parts Two and Three.
- The proposed alteration will not result in significant adverse environmental impacts or use conflicts.
- Due to conditions at the site in question, the standard will cause the applicant an undue hardship.
- The modification requested by the applicant is the minimum necessary to relieve an undue hardship
- The undue hardship is not the result of any prior action of the applicant.

A denitrification system is defined as any system which removes at least fifty percent of the total nitrogen loading measured on an average annual basis at the outlet of the septic tank (Olsen and Lee as amended, 1984). RICRMC requires these systems in specific areas by Section 320.2.B1 in the 1993 Addendum to the SPR SAMP. However, RIDEM must approve the design of these systems. The area these systems are required is specified in Part 2 of Section 320.2.B.1 in the SAMP, which is an area in the Green Hill Pond watershed. The RICRMC denitrification requirement lacks legislative and agency authority because RICRMC depends on RIDEM to approve design of these systems, and for agreement on the area they will be required. The new RIDEM ISDS regulations have approved two denitrification systems for use as alternative ISDS technology.

The RUCK system, designed by Dr. Rein Laak, separates grey water from black water and sends it to different septic tanks. The black water passes from its septic tank into a sand filter where the ammonium (NH_4+) is converted to nitrate (NO_3+). This effluent is then mixed with the grey water effluent and passes into an anaerobic tank or directly into a soil absorption system. The biochemical reactions between the grey water (a carbon source) and black water effluent should convert the nitrate to nitrogen gas, thus eliminating it from the waste stream (Gold and Wright, 1985). The singulair system is a trickling filter system which operates with a drain-field. This is one of the systems presently being used to study denitrification systems at the University of Rhode Island (Gold, 1994).

There are many different alternative systems which have a higher removal rate of nitrate-nitrogen than traditional ISDSs. The following systems are based on a United States Environmental Protection Agency (USEPA) Small Water Systems publication (USEPA, 1992):

<u>Pre treatment and Soil Absorption</u>

Pre treatment addresses the need to treat higher strength waste (such as from restaurants) and can help repair biologically overloaded systems where no additional absorption area is available. Aerobic treatment systems and filters can be used for this purpose. For aerobic treatment, wastewater and air mix in a tank. Bacteria grow in the tank and break down the waste. For filters, septic tank effluent passes over porous media that trap the solids. Bacteria that grow in the media break down the waste. Professional maintenance by certified operators and a lot of energy are required for aerobic systems.

<u>Septic Tank and Mound System</u>

Pumps dose effluent into a gravel bed or trenches on top of a bed of sand. Sandy soil carefully placed above the plowed ground surface treats the effluent before it moves into the natural soil. The system extends onsite system use in areas with high groundwater, high bedrock, or tighter clay soils. Regular inspection of the pumps and controls and flushing of the distribution network are needed.

Evaporation and Absorption Bed

Effluent from a septic tank or aerobic tank flows into gravel trenches or chambers in a mound of sandy soil. Less permeable soil placed at the surface of the mound helps shed rain from the system. Trees that grow around the system and plants on top of the system pull liquid from the sand and transpire the water into the air. Some effluent may seep into the soil. This system requires a climate where evaporation consistently exceeds rainfall.

Septic Tank, Sand Filters, Disinfection and Discharge

Open or buried beds of sand may receive single or repeated applications of effluent. Effluent passes through the media and drains from the gravel and pipe network below the filter. Effluent may be discharged to the environment directly or into a soil absorption or land treatment system. Disinfection often precedes discharge into a stream or land irrigation. Certain types of filters can significantly reduce nitrogen and may be used in areas where soil absorption is not possible. Requires inspection and periodic maintenance. Surface discharge requires management.

The vegetated buffers and nonpoint pollution control program policies only apply to new development and in cases where the footprint of an existing development is increased. Although the burden of proof is on the applicant, there is strong support for property rights in the takings case law[4] based on the Fifth Amendment Takings Clause (Kalo, 1990).

The institutional and regulatory approach to water quality management has significantly impeded the state's efforts in estuarine management. The process resembles the contemporary regulatory-intensive approach which relies heavily on rule-making rather than evaluation of the impact to aquatic resources (Courtemanch et al., 1989).

Cumulative Impacts:
"The tyranny of small decisions"(Kahn, 1966)

Although scientists, economists and other thinkers have espoused the existing and potential problems from cumulative impacts (Kahn, 1966 and Odum, 1982), impact assessment has typically evaluated only the potential effects of a single action on the environment (Leibowitz et al., 1992). The nonpoint source problems cropping up in our coastal communities are forcing managers from the federal government to the local planner to consider the problem of cumulative impacts. Cumulative impacts are defined as compelling effects which are formed by new and/or additional material of the same kind (Woolf, 1981). The result of small, seemingly harmless decisions about wetland conversion, small lot development, water use and redirection, sewer extensions and septic system use are today's evidence of the cumulative impacts of past management decisions:

- Coastal habitat and wetland loss have resulted in a decline of U.S. fishery stocks (U.S. Department of Commerce, 1994);
- Endangered and rare species habitat is fragmented;

[4]See Nolan v. California Coastal Commission. 483 U.S. 825 (1987).

- Public and private water supplies have microbial and nutrient pollutant problems;
- Nutrient enrichment from sewer outfalls, individual sewage disposal systems and agricultural fertilizers pose serious problems for sensitive nearshore waters.

The result of cumulative impacts are very evident in the coastal zone, the difficulty is deciding how to prevent them.

Communities are beginning to address cumulative impacts in part because nonpoint pollution problems require management of all the individual sources which contribute to the pollutant problem. These pollutant sources occur throughout watersheds and ecosystems, and may develop slowly over time. One of the most difficult nonpoint pollutant problems faced by coastal communities is from anthropogenic sources of nitrogen. Humans introduce nitrogen into the landscape from individual septic systems, home lawn and garden fertilizers, agricultural fertilizers, golf course fertilizers, domestic pets, farm animals, and car emissions in the form of nitrous oxides in precipitation. Such sources proliferate in coastal watersheds because more people live and want to live along the shore.

Population Increases

Several important facts support the need for research and documentation of the cumulative impacts of management decisions on nitrogen loading to coastal waters:

1. Over the next 30 years, global population is projected to grow by nearly two-thirds, from 5.5 billion to 8.5 billion (World Resources Institute, 1994).

2. Coastal states accounted for 83% of new U.S. homes authorized by building permit during the past two decades (Culliton et al., 1992).

3. 110 million people or almost one-half of the United States total population now live in coastal areas (Culliton et al., 1992).

4. By the year 2010, the U. S. coastal population will have grown from 80 million to more than 127 million, an increase of almost 60% nationwide (Culliton et al., 1992).

5. An epidemic of nuisance phytoplankton blooms--red and brown tides--is spreading in the sea, accompanied by marine mammal, fish, and invertebrate die-off, human death and illness, and ecosystem dysfunction (Jaworski, 1994).

Locally, the evidence of an increasing population and a penchant to live by the sea brings a clearer picture of the nitrogen pollution problem which coastal communities need to address. Although the National Ocean Service provides statistics that the coastal population in the Northeast will increase by 30 percent between 1960 and 2010 (Culliton et al., 1990), this does not reflect the influx of visitors these same coastal communities will experience during the popular summer and off-season months.

During the past fifteen years, the salt pond watersheds on the south shore of Rhode Island have experienced an increase in development. The region has become a popular summer retreat which is reflected in the additions to small summer cottages, an increase in the visitor population, and new development. Also, enlargement of U.S. Route 1 has made it possible for people to reside near the salt ponds and commute to the City of Providence. These changes in the region are reflected in the total number of houses within the six salt pond surface watersheds in this study which increased from 6208 in 1981 to 8910 in 1992 (Table 2), and in the permanent population which went from 19908 in 1980 to 27707 in 1990 (U.S. Census Bureau, 1980; U.S. Census Bureau, 1990).

Table 2. Number of housing units in the SPR by salt pond surface watershed, 1981, 1992 and buildout.

Watershed	1981	1992	% Increase	Buildout
Point Judith	1779	3079	173	4511
Potter	1362	1376	101	2662
Cards	433	475	110	1403
Trustom	61	133	218	219
Green Hill	1564	2364	150	3016
Ninigret	1009	1483	150	1917
Total	6208	8910	144%	13728

Problem Statement

Have the cumulative impacts of local, state and federal management decisions resulted in measurable changes in nitrogen loading to the Rhode Island salt ponds? Is it possible to identify changes in the source and transmission of nitrogen over a period of time, which managers can use to support local and state regulations which limit development in the watersheds of nutrient sensitive water bodies? By identifying significant changes within the salt pond watersheds over time, is it possible to show the cumulative impact of past management decisions?

Managers need to understand the cumulative impacts of land-use and development on the landscape because, among other things, these decisions affect coastal water quality. When Rosenberg considered the problem of nitrogen in his 1985 famous paper, "Eutrophication-the Future Marine Coastal Nuisance?" noted that severe environmental perturbations, such as mass mortalities of fish and benthic organisms, were necessary to arouse concern over the occurrence of eutrophication in marine areas. Over the last ten years, the rise of citizen monitoring groups and local concern for water quality has sensitized our understanding of small scale ecosystem disturbances. However, local management efforts in the Northeast to control nitrogen inputs to nearshore waters are not supported by municipal ordinances. There are notable exceptions which are discussed further in the Literature Review Chapter. Communities must recognize that human use of terrestrial and atmospheric resources is linked to the health of coastal water quality. People have realized the need to protect our groundwater resources to insure the safety of public and private drinking water. However, the relationship between coastal water quality and coastal development is not yet considered as vital to the human environment by a majority of the public.

Considering both the small and large scale changes in the quantity and potential movement of nitrogen in the salt pond watersheds, and local/state management initiatives over the last fifteen years, it will be possible to see changes in nitrogen input to the salt ponds.

Hypothesis

It is hypothesized that there has been an increase in nitrogen loading to the salt ponds between 1981 and 1995 based on calculations and field data for nitrogen transmitted through groundwater, precipitation, stream discharge and over-land runoff.

Approach to the Problem

I used two methods to measure the changes occurring in nitrogen loading over a fifteen year period to the salt pond. First, a budget of nitrogen loading to groundwater was calculated based on land-use and literature values for nitrogen loss to groundwater and field measurements of stream flux and atmospheric deposition. The second method compared nitrogen loading from actual groundwater measurements of nitrogen to the calculated groundwater loading; and the Paired Student t test was used to test for statistically significant differences between 1980 and 1994 groundwater samples. The final section will compare different methods of calculating or measuring over-land runoff to determine if national concentrations are similar to measured concentrations in Rhode Island.

The salt ponds in this study include six of the nine ponds on the south shore of Rhode Island; Point Judith Pond, Potter Pond, Cards Pond, Trustom Pond, Green Hill Pond and Ninigret Pond (Figure 3).

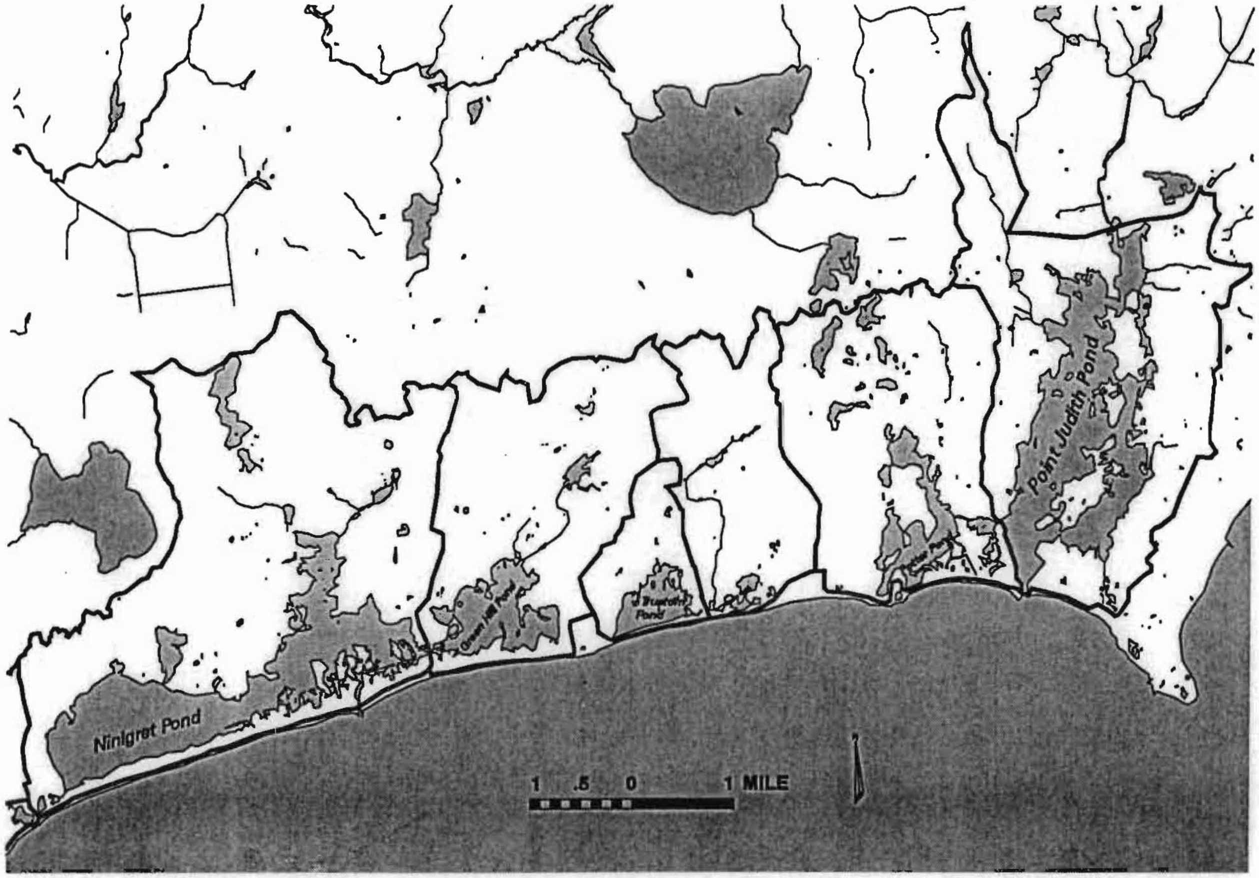

Figure 3. Rhode Island salt ponds watersheds and study area.

RIGIS, 1996 by URI Coastal Resources Center

Nitrogen loading to the ponds is defined as the total amount of nitrogen entering a salt pond from groundwater, streams, over-land runoff, and atmospheric inputs. The nitrogen loading budget includes calculations and field data for nitrogen transmitted through groundwater, precipitation, stream discharge and over-land runoff. The concentration of nitrogen in groundwater is based on samples from private homeowner wells taken in 1980 and 1994.

The nitrogen loading calculations for both 1980 and 1995 are based on approximations of actual nitrogen inputs to the salt ponds. Nitrogen is transmitted to the salt ponds by three paths: groundwater, wet and dry deposition, and stream flow. Groundwater is the largest source of fresh water to the salt ponds (Olsen and Lee, 1984). Nitrogen is lost to groundwater from septic systems, home lawn and garden fertilizer, agricultural fertilizer, and wet and dry deposition.

The 1980-81 nitrogen loading calculations completed by the University of Rhode Island Coastal Resources Center for the RICRMC SAMP were based on the 1978 Long Island Sound 208 Study (Koppleman, 1978). In this study, more recent literature values were used to calculate nitrogen loading to groundwater for both 1980-81 and 1994-95. Rainfall data from the U.R.I. Weather Station for 1980-81 and 1994-95 (U.R.I. Weather Station, 1980, 1981, 1994, and 1995) and wet and dry deposition of nitrogen from Fraher (1991) were used to calculate nitrogen loading from atmospheric inputs. Stream loading was determined from field measurements of flow and water samples collected by the author and analyzed for NO3 and NH3 by Betty Buckley at URI/GSO. Land-use areas within the watershed were determined from the 1988 land-use database of the Rhode Island Geographic Information Survey (RIGIS, 1988). The salt pond surface watersheds from RIGIS (RIGIS, 1995) together with 1981 and 1992 Rhode Island Statewide Planning aerial photos were used to determine the number of structures in each watershed. Other sources of information will be explained under the methods section.

Groundwater concentrations are determined from samples of the same wells used in the 1981 URI/GSO/CRC study. The Paired Student t Test (Dowdy and Wearden, 1983) is used to test for any significant differences in the groundwater concentrations between the two years 1980 and 1994.

Chapter 2

A Literature Review of Cumulative Impact Management

The assessment of cumulative impacts is recognized and identified as a necessary part of any environmental evaluation in many local, state and federal environmental review processes. However, most programs that do make explicit reference to cumulative impacts merely direct consideration of those impacts, without guidance on how they are to be considered (Vestal and Reiser et al., 1995). For example, the administrative rules of the Wisconsin Department of Natural Resources requires consideration of "the extent of cumulative effects of repeated actions of the same type, or related actions or other activities occurring locally that can be reasonably anticipated and that would compound impacts" (Wisconsin Administrative Code, 1987 as stated in Perry, 1990). The problem with this statute and many other state statutes is that although there is a requirement to identify potential cumulative impacts, the statute does not describe how to evaluate them in respect to additional development occurring in the area. This has also been a problem with the 1969 National Environmental Policy Act (NEPA) (42 U.S.C. §4321 et seq., 1969) environmental impact assessment process.

The concept of cumulative impact management has been a part of our national environmental policy since the Council on Environmental Quality (CEQ) guidelines (40 C.F.R. §1508.9 et seq., 1978) mandated federal agencies to identify the cumulative impacts of major federal actions. The addition of cumulative impacts to the range of environmental impacts which must be considered under NEPA, was preceded by several Federal district court case decisions which addressed cumulative impacts both directly and indirectly. These decisions defined, and interpreted federal agency responsibility to evaluate cumulative impacts under NEPA. Specifically, *Scientists' Institute for Public Information, Inc. v. Atomic Energy Commission, (481 F.2d 1079 D.C. Cir. 1973)*, challenged the intent of NEPA in respect to the timing of an Environmental Impact Statement (EIS) on a program for Liquid Metal Fast Breeder Reactors (LMFBR) (481 F.2d 1088 U.S. Court of Appeals, D.C. Circuit 1973). The plaintiffs asserted an EIS was required for the program because it involved a recommendation or report on proposals for legislation and other major federal actions significantly affecting the quality of the human environment (481 F.2d 1079 U.S. Court of Appeals, D.C. Circuit 1973). The case is significant for cumulative impact management because the Atomic Energy Commission (AEC) claimed that an EIS was not necessary for the overall program of the LMFBR. Instead, the AEC claimed that "analysis of the broader aspects of the total program take place within statements on individual facilities" (481 F.2d 1085 U.S. Court of Appeals, D.C. Circuit 1973). The AEC did not intend to consider the overall impacts of the LMFBR program even though the program would include many different sites and reactors, which together had serious environmental considerations. The AEC only looked at the site specific impacts from each reactor. For instance, just one of the significant environmental threats which would not be apparent to the public (without a NEPA statement) included 600,000 cubic feet of high-level concentrated radioactive wastes which would be generated by the year 2000 (481 F.2d 1098 U.S. Court of Appeals, D.C. Circuit 1973). This figure only came out in the AEC's answer to the complaint in this case, and notably was not part of the information presented in the AEC's EIS on the first demonstration plant (breeder reactor) (481 F.2d 1098 U.S. Court of Appeals, D.C. Circuit 1973). On appeal, the U.S. Appellate Court for the D.C. Circuit found that there was considerable evidence that the LMFBR program had advanced to such a point where an EIS should be prepared under the authority of Section 102(2)(c) of NEPA.

In a second case, *Natural Resources Defense Council v. Callaway (I524 F.2d 79 U.S. Court of Appeals, Second Circuit 1975)*, a suit was brought against the Secretary of the Navy by environmental and citizens groups who sought relief against further dumping by the Navy of contaminated dredge spoils at the New London dump site in Long Island Sound (1524 F.2d 79 U.S. Court of Appeals, Second Circuit 1975). The plaintiffs claimed, among other things, that the Navy's final EIS for disposal of polluted dredge material at the New London dumping site in Long Island Sound failed to meet NEPA standards because it did not discuss the cumulative impact of other dumping and dredging projects in the New London area on the ocean environment (1524 F.2d 80 U.S. Court of Appeals, Second Circuit 1975). The U.S. Court of Appeals, Second Circuit, decided that the U.S. Navy's final EIS, in respect to dumping of polluted dredged material at the New London dump site in Long Island Sound, failed to meet NEPA standards because the statement did not discuss other dumping and dredging projects in the New London area and their cumulative impact, on the ocean environment. These cases influenced the 1978 CEQ guidelines and laid the foundation for cumulative impact management which now applies to all Federal agency legislation or major Federal actions.

In addition to NEPA, there are other Federal agencies and programs which consider cumulative impacts. The common problem is that guidelines for these programs do not address the methodology to be used for assessment of cumulative impacts, nor the weight they should be given in environmental decision-making (Vestal and Rieser et al., 1995).

Section 404 Program

Section 404 of the Clean Water Act allows the United States Army Corps of Engineers (Corps) to prohibit a discharge to coastal waters which would "cause or contribute to significant degradation of the waters of the United States" (40 C.F.R. § 230.10(c)). Section 230.11 of the Clean Water Act requires the permitting authority to determine in writing the potential short-term, or long-term effects of a proposed discharge of dredged or fill material on the physical, chemical, and biological components of the aquatic environment (40 C.F.R. § 230.11). Among the factors to be determined are cumulative impacts, cumulative effects and secondary effects. Cumulative impacts are defined as the "**changes in an aquatic ecosystem that are attributable to the collective effect of a number of individual discharges of dredged or fill material**" (40 C.F.R. §230.12(g)) (Emphasis Added). Cumulative effects are "**effects attributable to the discharge of dredged or fill material in waters of the United States, and are to be predicted to the extent reasonable and predictable**" (40 C.F.R. §230.12(g)(2)) (Emphasis Added). Although examples of secondary effects on aquatic ecosystems are provided in section 230.12 (h)(2), there is no guidance as to how the permitting agency is supposed to quantify or determine if the cumulative impacts are great enough to deny a dredge or discharge permit.

United States Fish and Wildlife Service

The United States Fish and Wildlife Service (USFWS) approach to cumulative impact management depends on federal inter-agency cooperation (Vestal and Reiser et al., 1995). Once the problems have been identified, described and researched through a review of the literature, the inter-agency group determines the causes and seeks through inter-agency cooperation a resolution to the problem. The final step is a plan identifying a series of specific corrective actions for the problem.

Samuel C. Williamson, a USFWS research ecologist, recommends that an important part of the cumulative impact assessment is finding simple techniques to resolve complex problems. For instance, the Chesapeake Bay Project uses submerged aquatic vegetation (SAV) as an indicator of water quality. SAV can be measured and then correlated with the abundance of migratory fish and wildlife species (Vestal and Reiser et al., 1995) to indicate the effect of cumulative impacts.

The National Oceanic and Atmospheric Administration's Coastal Ocean Program

The 1992 program guidance for the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Sea Grant College Program notes that there are few methods which effectively assess the cumulative impacts of human actions in the coastal zone, nor are there regulatory guidelines facilitating such procedures (U.S. Department of Commerce, 1991b). In fact, cumulative impact research and assessment to date has tended to be resource specific and natural science based (University of California Sea Grant College, 1993).

The NOAA Coastal Ocean Program recently published "Methodologies and Mechanisms for Management of Cumulative Coastal Environmental Impacts." The publication is the result of three years of study at the University of Maine's Marine Law Institute and the NOAA National Marine Fisheries Service's Northeast Region, and was funded by NOAA's Coastal Ocean Program (Vestal and Reiser et al., 1995). This is the first attempt by a government agency to look at the way local, state, and Federal government manage cumulative impacts.

In the past, research at the Federal and university levels focused on cumulative impacts from wetland alterations and losses (Bedford and Preston, 1988; Stakhiv, 1988; Hirsch, 1988; Brinson, 1988; and Gosselink, Shaffer, Lee, Burdick, Childers, Leibowitz, Hamilton, Boumans, Cushman, Fields, Koch and Visser, 1990). Presently, the U.S. National Science and Technology Council recognizes the need for long-term measurements to document changes in inputs of nutrients to estuaries (National Science and Technology Council, 1995). In addition, the U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, is compiling a list of nationwide data sources to be used as a tool for regional assessment of cumulative impacts (John Hay, personal communication, 1995). The need to develop methodologies for cumulative impact assessment is being met by an integrated effort of both federal and state cooperation. This very positive approach involves federal agencies, coastal councils, universities, and local communities. Following is a brief description of the types of cumulative impact initiatives occurring at various levels of government and academia.

Federal-State-Local Initiatives to Manage Cumulative Impacts

Section 309 of the 1990 amendments to the Coastal Zone Management Act identified the cumulative impacts of population growth and development as a priority problem area for state coastal management programs (16 U.S.C §309). As a result, several cumulative impact studies are funded through section 309 grants and the National Sea Grant Program. A brief explanation of each study follows:

Monterey, California

The University of California, California Sea Grant College is just finishing a two year research project analyzing the cumulative impacts resulting from the California Coastal Act (University of California Sea Grant College, 1993). The research hypothesis tests whether incremental, project-by-project decision-making by the California Coastal Commission and local decision-makers has undermined the comprehensive resource protection policies of the Coastal Act (University of California Sea Grant College, 1993).

Kenai River, Alaska

Another Section 309 project entitled the "Assessment and Control of Cumulative Impacts of Coastal Uses on Fish Habitat of the Kenai River, Alaska," was coordinated by the Alaska Coastal Management Program and the Alaska Department of Fish and Game, Habitat and Restoration Division. The program was designed to identify and evaluate the cumulative impacts of development actions including public and private land-use impacts on Kenai River fish habitat (Fink, Rozen and Seaman, 1993). The Habitat and Restoration Division used a non-regulatory strategy to encourage landowner participation in the conservation and protection of natural resources. These objectives were accomplished through education and positive incentives, in an effort to increase the attractiveness of conservation activities.

The Salt Pond Region, Rhode Island

The Rhode Island Coastal Resources Management Council is in the process of revising the 1984 SAMP for the SPR of Rhode Island. As part of this process, and through funding from a Clean Water Act Section 309 grant, RICRMC is completing a "Cumulative and Secondary Impact Study of

Development." The project is based on the premise that the SPR supports resources and uses which can be negatively impacted by increased nutrient sources associated with more development. Salt pond resources and uses include the following: shell fisheries; spawning and nursery habitat for several important recreational fisheries; recreational boating, a commercial fishing fleet, and an attractive destination to visitors. The objectives of the project include an evaluation of both the cumulative and secondary impacts of pollutant loadings; development of revised watershed and critical area boundaries; additional regulatory requirements for development activities, and policies and recommendations for the new SAMP. The technical work for this study is being completed by the University of Rhode Island Coastal Resources Center.

Buzzards Bay, Massachusetts

There are also federal and state initiatives which indirectly manage cumulative impacts. These programs are generally oriented to a particular resource like wetlands, water quality, or habitat loss. The U.S. Environmental Protection Agency through the National Estuary Program, and the Massachusetts Executive Office of Environmental Affairs, participate in a project to develop and implement management recommendations that will preserve and protect water quality and living resources in Buzzards Bay (Costa, Howes, Giblin and Valiela, 1992). The specific purpose of this program is to quantify nitrogen loading within the Buzzards Bay watershed. The project also measures cumulative impacts as it records both past and potential impacts of new development on water quality in the bay.

The Chesapeake Bay Program

The state of Maryland, the Commonwealths of Pennsylvania and Virginia, the District of Columbia, the Chesapeake Bay Commission, and the EPA are partners in the Chesapeake Bay Program. Since the signing of the 1983 Chesapeake Bay Agreement, federal, state, and local governments have worked together to reduce nutrients entering the Bay 40 percent by the year 2000 (Chesapeake Bay Program, 1995). As part of the effort to reduce nitrogen loading to Chesapeake Bay, federal and state partnerships have considered all of the sources of nitrogen which contribute to the Bay in order to address the cumulative impacts of various land-use practices.

Waquoit Bay Estuarine Research Reserve, Massachusetts

The National Science Foundation, EPA and NOAA are all part of the Waquoit Bay Land Margin Ecosystems Research Project. This project is a regional scale experiment in nutrient loading intended to examine the major components of coastal landscapes and how they are coupled by nutrient transport and transformations. The objective is to show that differences in the land-uses among subwatersheds result in differences in the rate of nutrient loading to groundwater and hence to receiving waters (Waquoit Bay National Estuarine Research Reserve, 1992)

Local and State Initiatives

Maine

The Marine Law Institute at the University of Maine Law School with support from the Maine/New Hampshire Sea Grant Marine Advisory Program recently published a pamphlet about "Managing Cumulative Environmental Impacts of Coastal Development." The question raised in this pamphlet is how to evaluate and regulate incremental development. The issue is explored from the perspective of Maine's local planning boards. The publication is meant to be an introduction and guide for resource users, and examines how Maine law allows for consideration of cumulative impacts (Maine School of Law, Marine Law Institute, 1995).

Maine began considering the implications of cumulative impacts in 1985. The Governor's Coastal Advisory Committee identified the pressures and cumulative effects of growth as the most critical issue facing the coast of Maine, and asked the Maine State Planning Office to explore what Maine could do to anticipate such effects (Dominie, Holly and Scudder, 1987). The major conclusion of the State Planning Office report was that negative cumulative effects were caused by growth in the absence of an overall plan. Planning was identified as the tool which could anticipate and appropriately site land-uses to avoid harmful impacts. The State Planning Office defined cumulative impacts as the overall changes which take place as an area grows over time, house-by-house, building-by-building, development-by-development. The sum of all the changes gradually produces impacts which far surpass the individual effect of any single project (Dominie, Holly and Scudder, 1987).

Town of Falmouth, Massachusetts

The Falmouth Nutrient Loading Bylaw is an approach toward minimizing the effects of nutrients upon fresh and coastal water systems. The Bylaw is the result of a nutrient analysis of Buttermilk Bay and it's watershed. Buttermilk Bay is a shallow, semi-enclosed coastal embayment situated at the northern end of Buzzards Bay, Massachusetts (Valiela and Costa, 1988). Inputs of nutrients into groundwater and the bay were estimated from major sources in the watershed. The bylaw is based on the presumption that housing density within the watersheds of fresh and coastal ponds is related to water quality. The bylaw allows the town to regulate through zoning and subdivision controls, the amount of nutrients entering the town's water systems .

Cape Cod, Massachusetts

The Cape Cod Nonpoint Source Management Plan was initiated to protect the water quality of selected embayments on Cape Cod (Eichner, 1992). The results of the project will help towns to plan for effective management of their waste water by determining the appropriate levels of development in their coastal watersheds.

Methodologies for Cumulative Impact Evaluation

There is no single, generally accepted, comprehensive environmental assessment methodology for cumulative impacts (Vestal and Rieser et al., 1995). However, there are basic similarities in the research and methods which have actually been used to consider cumulative impacts for wetlands (Gosselink and Lee, 1987). These include studies dealing with sedimentation from various land-uses (Dickert and Tuttle, 1985), fisheries habitat (Liepitz, 1994), the capacity of public service systems (Dickert and Sorensen, 1976) and coastal development. All of these resource issues have considered the following information to be necessary to an assessment of cumulative impacts:

- Identification of the relevant ecological system and its boundaries.
- System thresholds (when they can be pre-determined).

- Explicit time boundaries.
- Goal setting for the health of the resource.
- Identification of cumulative impact sources.
- Identification of institutional barriers to resource management.

There are other principles of cumulative impact assessment which are appropriate to different resources. Each cumulative impact methodology will be different depending on the resource and the political realities of institutional jurisdiction. The following is a brief description of better known methodologies.

Environmental Protection Agency Synoptic Approach

The Wetlands Research Program (WRP), within EPA's Office of Research and Development, created a risk-based approach to wetland assessment that allows evaluation at three different spatial scales: site-specific, at which the function of individual wetlands is assessed; regional, at which relative comparisons are made between wetlands within the same watershed; and inter-regional, in which relative comparisons are made between landscape sub-units by considering the aggregate characteristics of wetlands within those sub-units (Leibowitz et al., 1992). The synoptic approach was designed for making comparisons at the inter-regional scale so that regulators could include information on the cumulative impacts of wetland loss during review of permits for proposed discharges under Section 404 of the Clean Water Act (Leibowitz et al., 1992). The synoptic approach to cumulative impact evaluation provides a framework for comparison of synoptic indices or landscape variables between landscape sub-units. Sub-units include watersheds, counties or ecoregions (Leibowitz et al., 1992).

Landscape units and variables are used as indicators for cumulative impact assessment because of management concepts found in systems ecology, landscape ecology, and risk assessment. These three disciplines together evaluate the interactions within ecosystems, between ecosystems, and the risk of human actions within the ecosystem (Leibowitz et al., 1992). The synoptic approach uses four indicators of landscape stress: function, value, functional loss, and replacement potential. Because environmental regulations target activities, an important step in the synoptic approach is the identification of the activities or impacts and the ecological response (the effect)(Leibowitz et al., 1992).

Although the synoptic approach was developed for wetland evaluation, the landscape based principles and stress related indicators are applicable to nonpoint pollutant problems in coastal watersheds. In the case of nonpoint pollution, the activities are not as obvious as the dredging and fill of wetlands. Nevertheless, associating landscape activities and their effects on the resource is an important step in cumulative impact assessment.

Alaska's Assessment of Cumulative Impacts on Fish Habitat in the Kenai River

The Alaska Department of Fish and Game (ADF&G) Habitat and Restoration Division assessment of the cumulative impacts of development and human uses on fish habitat in the Kenai River was undertaken with funding from the Coastal Zone Enhancement Grants program under Section 309 of the Coastal Zone Management Act. Because funding constraints prevented a watershed based study, the ADF&G used a strategic/detailed assessment approach that would focus on a smaller geographic area emphasizing the core problem (Vestal and Rieser et al., 1995). The assessment methodology involved the following steps:

- Identification of the target resource and development of a fish habitat classification scheme for impact assessment purposes.
- Development of a baseline description of the conditions occurring along the river correlated to individual land ownership patterns.
- Selection and application of a qualitative fish habitat value model procedure.
- Completion of a development trends analysis.
- Modeling of future changes in habitat characteristics.

U.S. Army Corps of Engineers Cumulative Impact Analysis of Wetlands Using Hydrologic Indices

Nearly all significant wetland processes can be wholly or partially described in hydrologic terms (Nestler and Long, 1994). Consequently, many wetlands can be characterized in terms of their alterations on the hydrologic regime (Scholosser, 1991; Ehrenfeld and Schneider, 1991 as noted in Nestler and Long, 1994). The U.S. Army Corps of Engineers (Corps) authorized a study to assess the cumulative impacts of wetlands by relating historic patterns of flow, derived from the stream's flow record, to changes in the watershed associated with that stream. The study area chosen included selected streams in the White River basin, Arkansas/Missouri. Using nonlinear, harmonic analysis,[5] and time-scale analysis, to reveal the time-dependent patterns in the respective samples, the results were compared

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[5]Harmonic analysis evaluates the fit of a time series of data to a harmonic (usually cosine or sine) function. Harmonic analysis typically generates four coefficients -mean, period, phase, and amplitude - that can be used to describe a process that approximates a harmonic function (Nestler and Long, 1994).

decade-by-decade to determine changes in the historic and seasonal patterns (Nestler and Long, 1994).

The Corps approach to cumulative impact evaluation for wetlands is useful if managers have the necessary data, and they are working with freshwater wetlands (which can be impacted by stream flow). Otherwise, the Corps approach is a limited management tool because it is dependent on stream flow data which may not be readily available for smaller streams; and the approach does not apply to coastal wetlands which are impacted by other factors like sea level rise and sedimentation.

Landscape Conservation Approach in Forested Wetland Watersheds

Gosselink developed a landscape approach to address the effects of human activities on bottomland hardwood forest ecosystems (Gosselink et al., 1990). The overall project was coordinated by The Nature Conservancy and included participants from federal, state, and local government agencies, universities, conservation organizations, private industry, and private citizens. Funding for the project was provided by the National Wetlands Research Center, U.S. Fish and Wildlife Service, EPA through the Louisiana Department of Environmental Quality Nonpoint Source Program, and The Nature Conservancy (Vestal and Riser et al., 1995).

The landscape approach was utilized because of the following reasons:

- Cumulative impacts are usually landscape level phenomena.
- A landscape focus can conserve valued attributes that are not manageable at a larger scale.
- The natural system is optimal and self-maintaining.

- Landscape conservation also conserves the valued functions of biota of smaller subsystems (Gosselink and Lee, 1987).

The landscape approach has three basic steps which include ecological assessment, goal-setting, and implementation. Ecological assessment involves determining the ecological "health" of the study area.

Collaborative Land-Use Planning

There have been several cumulative impact case studies completed by the University of California, Berkeley's Institute of Urban and Regional Development. These studies were supported in part by funding from NOAA, Office of Sea Grant, and the California Resources Agency. *Collaborative Land Use Planning for the Coastal Zone* is the result of research aimed at developing methods for managing the cumulative impact of coastal development, and evaluating the collaborative planning process as mandated by the California Coastal Act (Dickert et al., 1976). The *Collaborative Land Use Planning for the Coastal Zone* report includes two volumes. The first volume discusses the methods for cumulative impacts assessment. Specifically, the first volume states the primary purpose of impact assessment of land-use plans and zoning ordinances lies in its evaluation of the cumulative effects of development -- effects that cannot be determined on a project-by-project basis. The key areas cited for impact assessment in local coastal programs are those impacts which result from a specified land-use pattern, population level, and/or level of facility development (Dickert et al., 1976).

Impact assessment is described as a means of measuring how land-use designations are in conflict with coastal policies; the extent to which public service capacities are exceeded by the increased levels of population; the extent to which the "carrying capacities" of any natural systems are exceeded by the amount of development allowed; and the extent to which planned development is allowed adjacent to a resource area, so as to present an adverse impact, threat, or use conflict (Dickert and Sorensen, 1978). Collaborative planning is offered as a method to evaluate cumulative impacts, and requires that state and local units of government work jointly to prepare and implement local, regional, or state land-use plans. The second volume illustrates the application of the collaborative planning process and related analytical methods to the Half Moon Bay subregion of San Mateo County, California (Dickert et al., 1978). The methodology for cumulative impact analysis focuses on the problems associated with the capacity of public service systems in the Half Moon Bay subregion.

Elkhorn Slough Estuary

Another cumulative impact problem in California focused on the impact of land uses on wetlands within the estuarine complex of the Elkhorn Slough subregion. In 1981, the Elkhorn Slough was designated as a National Estuarine Sanctuary under Section 315 of the Federal Coastal Zone Management Act (16 U.S.C §315) (Now renamed the Elkhorn Slough National Estuaries Research Reserve). The estuary sanctuary program was aimed primarily at the acquisition of wetlands with little recognition of proposed land use changes and related impact from the adjacent watershed areas (Dickert and Tuttle, 1985). However, through the collaboration of the Estuary Program and the local coastal program, there was more opportunity to use the regulatory process together with wetland acquisition.

Components involved in the cumulative impact assessment included:

- Hydrologic assessment of runoff and sediment transport.
- Field measurements of erosion and deposition resulting from various land-uses throughout the basin.
- Photogrammetric analysis of wetland and upland change spanning a fifty year time period.
- Measurement of site disturbance associated with dominant land-uses were components involved in the assessment (Dickert and Tuttle, 1985).

Measurements of these components were used to identify an acceptable amount of land-use change over time. Thresholds were determined based on the historic rate of land-use change and resulting resource damage, rather than the tolerance of the ecosystem to land-use change (Dickert and Tuttle, 1985).

Conclusions From a Review of the Literature

How do we know when cumulative impacts are a problem? The preceding literature and program review indicates that coastal resource managers have not been able to successfully answer this question. Cumulative impacts are difficult to measure, standardize, and forecast. Managers are just now beginning to monitor the changes necessary to understand how cumulative impacts affect wetland loss, water quality degradation, and a host of other natural resource problems. This review also offers a glimpse of what actions coastal communities are taking to protect their natural resources against cumulative impacts. Control of development through zoning is probably the most common method, but resource accounting, program evaluations and non-regulatory initiatives are also part of the management process. The literature on cumulative impacts does not address how local coastal managers can change the permit by permit decision-making process to a management regime which considers cumulative impacts. Both the Corps and EPA have broad mandates which permit them to consider cumulative impacts as part of the permit decision-making process. There are also federal court cases which support federal agency consideration of cumulative impacts.

Creating a regulatory regime which protects coastal resources from the effects of cumulative impacts is more difficult for state coastal councils and local governments. The Kenai River assessment does look at the potential acreage of salmon habitat and what has been lost due to human intervention; however, the study does not directly link specific management decisions to habitat degradation. Establishing a link between the management decisions which resulted in particular cumulative impacts is important because it provides a foundation to support land-use regulations and policies which prevent cumulative impacts.

Changes of nitrogen loading to the SPR of Rhode Island were measured in an effort to determine how management decisions have impacted nitrogen loading to the salt ponds between 1980 and 1995. The assumption is that by measuring the sources of nitrogen in the watershed of the salt ponds in 1994-95, and comparing the results to data collected in 1980-81, it will be possible to relate changes in nitrogen loading to various management decisions and population growth. Considering the changes in nitrogen loading and the changes in land-use and human activities, we should be able to determine the cumulative impact of development and human activity in the salt pond watersheds.

Chapter 3

Methods and Results

As stated previously in the *Approach to the Problem* section, there are two approaches which will be used to test the hypothesis that there was an increase in nitrogen loading to six of the salt ponds in the region between 1980 and 1995. There are calculations and field data for nitrogen transmitted through groundwater, precipitation, stream discharge and over-land runoff. Following is an explanation of the methods used and results obtained from each approach.

Method #1: The Calculated Salt Pond Nitrogen Loading Budget

The calculated nitrogen loading budget for Point Judith, Potter, Cards, Trustom, Green Hill, and Ninigret Ponds is based on four different loading paths to the salt ponds:

- Groundwater
- Streams and River
- Over-land Runoff
- Precipitation

Groundwater Loading

Nitrogen loading from septic systems, agriculture, fertilized playing fields, lawn fertilizer, domestic pets, and atmospheric deposition on undeveloped lands will be calculated for each salt pond watershed. The methods and results for each source are broken down by section, followed by a calculation sheet. The calculation method or model is based on the number of units or area of land-use and the loading rate for a source. The loading rate is based on the literature value for the particular land-use. The final section includes a calculated data sheet with the total nitrogen loading for each source by watershed.

The form of nitrogen considered for the loading budget is dissolved inorganic nitrogen (DIN) [Ammonia (NH_3) + Nitrate (NO_3)] unless otherwise indicated. Literature values for nitrogen loss to groundwater assume that NH_3 is converted to NO_3 (Gold et al., 1990). For atmospheric deposition and stream flux directly to the salt ponds, DIN is focused on as the major form of inorganic nitrogen loading into the ponds since DIN is usually the major nutrient regulating algal growth in coastal marine waters (Nixon et al., 1982).

An important variable in the amount of nitrogen entering a septic system is the number of people per housing unit. Because the non-resident population increases the total population of a salt pond watershed, an accurate accounting of the non-resident population was necessary to calculate nitrogen loading from ISDS to groundwater. The increase from non-resident population used in this research does not reflect a quantitative survey of population, but is an estimate based on a study completed by the Army Corps of Engineers for flood evacuation in Misquamicut, Rhode Island (1995). The 1980 and 1990 Census Data for General Housing Characteristics in Rhode Island, under the category of median number of people occupying year-round housing, represents the residential population (Table 3). Occupancy per house was averaged between towns where a watershed crossed town boundaries.

Table 3. Median persons per year-round housing unit in 1980 and 1990 (U.S. Census Bureau, 1980 and 1990).

Town	1980 Median # of persons	1990 Median # of persons
Narragansett	2.35	2.31
South Kingstown	2.4	2.32
Charlestown	2.33	2.3

The non-resident population in the SPR includes students attending the University of Rhode Island (URI) during the fall, winter and spring, and the spring, summer, and fall visitor populations. According to the State of R.I. Department of Economic Development, a tourism economist at the University of Rhode Island, and comprehensive plans for the towns of Narragansett (1994), South Kingstown (1995), and Charlestown (1991), there are no accurate estimates of seasonal population for southern Rhode Island (Personal Communications: State of R.I. Department of Economic Development; Dr. Tim Tyrrell, University of Rhode Island, comprehensive plans for the towns of Narragansett (1994), South Kingstown (1995), and Charlestown (1991)). There are some estimates available for seasonal population in southern Rhode Island, but these population estimates are either not watershed or town based, or they are not verifiable. These approximations include the following:

- Between 25,000 and 27,000 visitors stopped at the Charlestown Chamber of Commerce Visitor Center between Memorial Day and Columbus Day, 1995 (Charlestown Chamber of Commerce, Personal Communication, 1996).

- Sixty percent of the 14,253 URI students live off campus and some students reside in the salt pond watersheds (University of Rhode Island Off Campus Housing Office, personal communication, 1996).

- Seasonal population as estimated by the U.S. Army Corps of Engineers in a Misquamicut Beach Hurricane Evacuation Study for Westerly, Rhode Island (U.S. Army Corps of Engineers, 1994).

- U.S. Census data gives percentages of seasonally used houses (U.S. Census Bureau, 1980; U.S. Census Bureau, 1990).

The problem is not simply accounting for the increase of people occupying residential homes in the salt pond watersheds during the vacation season. In addition there are visitors who stay at hotels, and use facilities located at restaurants and beach pavilions. The estimate used here is based on the ratio of the resident to non-resident population used in the ACOE Misquamicut Beach Hurricane Evacuation Study (1995). In this study the non-resident population increases the resident population by 32% in Narragansett, 27% in the South Kingstown, and 67% in Charlestown (ACOE, 1995). The ACOE study does not specify how the population increases were determined, only that seasonal population is based on data reported in the 1990 census (ACOE, 1995). In order to get the percentage of increase due to non-resident populations, on a watershed basis, I took the same percentage of increase given in the ACOE study, of the median number of people per house (U.S. Census Bureau for 1980 and 1990) in each of the towns. Table 4 shows the median number of non-residents per house in Narragansett, South Kingstown, and Charlestown.

The loading estimate for seasonal populations are probably higher in this study than actual because they are not time-averaged, and do not consider specifically the number of hotel accomodations, restaurants and use of public facilities. This approach was used because the ACOE ratio of resident to non-resident populations is based on a resident population for the whole town and not just the salt pond watershed. Consequently, I am using the percentage of non-resident population increase from the ACOE estimate (which is based on the entire town) and applying it to the resident population in the salt pond watersheds (which is based on the 1980 and 1990 Census Bureau data and the number of structures counted in the 1981 and 1992 aerial photos).

Table 4. Non-Resident median population per house based on the 1995 U.S. Army Corps of Engineers Misquamicut Beach Study.

Town	1980 Non-Resident	1990 Non-Resident
Narragansett	0.76	0.67
South Kingstown	0.69	0.65
Charlestown	1.56	1.41

The 1980 U.S. Census Bureau median number of persons occupying year round housing units (Table 3) plus the non-resident median number (Table 4) was multiplied by the number of structures in each watershed to determine the total number of people living in the watersheds in 1981 and 1992 (Table 5).

Table 5. Median Permanent and Seasonal Populations in each salt pond watershed, based on the ACOE (1995) ratio of non-resident to resident popoulation and the U.S. Census Bureau data for median number of people per house in 1980 and 1990.

Watershed	Permanent Population		Seasonal Population		Total	Total
	1980	1990	1980	1990	1980	1990
Pnt. Judith	4234	7205	1299	2032	5533	9237
Potter	3269	3192	940	894	4209	4086
Cards	1039	1102	299	309	1338	1411
Trustom	146	309	42	86	188	395
Green Hill	3707	5461	1720	2364	5427	7825
Ninigret	2351	3411	434	2091	2785	5502

Septic Systems

The total number of septic systems for the two time periods (1980 and 1995) was determined from Rhode Island Statewide Planning 1981 aerial photos (scale 1"=400') and RICRMC 1992 aerial photos (scale 1"=250'). The surface watershed of each salt pond is delineated by the RICRMC 1994-95 Salt Pond database compiled at the URI Coastal Resources Center (RIGIS, 1995). The number of structures was counted without distinguishing between commercial and residential development. Since portions of the Point Judith Pond watershed are sewered, the town sewer map was used with the surface watershed boundary and the aerial photos to determine which houses were on public sewer. It was assumed that all the houses on a sewered street would be connected (Town of Narragansett, personal communication, 1994). A total of 526 structures was subtracted from the Point Judith Pond watershed.

The nitrate-nitrogen loading rate from a septic system is approximately 3.2 kg/N/capita/yr (Gold et al., 1990). Results of the calculations for nitrogen loading from septics for each salt pond watershed are shown in Appendix A-1.

Lawn and Garden Loading

The area for lawns and gardens was calculated by multiplying the number of structures in each watershed for 1981 and 1992, by 464.5m^2 (Cape Cod Commission, 1992). The nitrate-nitrogen loading from lawns and gardens is based on Gold et al. 1990 field results for an actual fertilized home lawn, where lysimeters were placed underground to collect rainfall and runoff percolate. The calculations are based on an application rate of 98.7 kg/N/acre/yr to a residential lot with 3.8 kg/N/acre/yr lost to groundwater

(3.9 percent of the nitrogen lost to groundwater). Results of the calculations for each salt pond watershed are shown in Appendix A-2.

The area of home lawn and garden which is fertilized is based on the Cape Cod Commission 1992 estimate of nitrogen loading to groundwater. The estimate of lawn size fertizlied assumes that every structure counted from the aerial photographs has a fertilzize lawn area of 464.5m^2. A survey of residential application rates completed on Long Island, NY found lawn sizes to be fairly constant averaging 36%-40% of total lot size in all categories except extremely low and high densities (Nassau-Suffolk Regional Planning Board, 1978 as cited by Eichner, 1992). Detailed surveys of actual lawn care practices in Prince William County, Virginia found 79% of suburban lawns were fertilized in the preceding year (Schueler, 1994). Less than 20% of residents tested their soil to determine whether their yard actually needed fertilization (Schueler, 1994).

Agriculture Loading

Loading for agriculture was based on 40.5 kg/N/acre for row cropped corn (Gold et al., 1990). Using tilled row crops with an application rate of 95.5 kg/N/acre/yr, the mean flow-weighted soil-water percolate concentrations of nitrate-nitrogen ranged from 4.45 mg/l in the spring of 1987 to 28.39 in the fall of 1988 (Gold et al., 1990). Mean annual concentrations for 1987 and 1988 were 4.17 mg/l and 17.46 mg/l respectively (Gold et al., 1990).

The area of land in agriculture in 1980 is based on the 1988 RIGIS land-use database. Since areas for row crop agriculture were not specified in 1980, it was assumed that the area of land used for agriculture did not change between 1980 and 1988. The 1995 agricultural land-use areas were based on information from the respective farmers in the Potter, Cards, Point Judith, and Trustom Pond watersheds. The 1988 land-use data were used for Green Hill and Ninigret Ponds in 1980-81 and 1994-95. The fertilizer application rate for corn is based on Gold et al., 1990, because these rates fell between the rates applied for row crop corn (40.8 kg/acre and 136.1 kg/acre) (Foster C. Browning and B.S. Carpenter, Personal Communication, 1995). This estimate of fertilizer application was used for all agricultural areas in 1980-81 and 1994-95. Fertilizer application probably varies in the SPR because some farmers base application rates on soil testing results, use different methods of application, and may use a cover crop. Hay fields were not considered for their nitrogen input to groundwater because they act as a sink to any fertilizer applications (Art Gold, personal communication, 1995). Beaulac and Reckhow (1982) also note that pasture and grazing activities retain soil and nutrients because of a continuous annual vegetative cover. Consequently nutrient fluxes from these land-uses are not included in the budget. Appendix A-3 shows the total nitrogen loading to groundwater from agriculture.

Domestic Pets

The dissolved inorganic nitrogen (DIN) loading factor for domestic pets is based on the 1978 Long Island Sound Study (Koppleman, 1978). The Long Island Sound Study used a factor of 0.19 kg/DIN/person/yr. Domestic pet nitrogen loading was calculated by using the U.S. Census bureau data for 1980 and 1995, and multiplying the number of people per house by the number of structures within the watershed from the 1981 and 1992 aerial photographs. Calculations for nitrogen loading from domestic pets for each of the salt pond watersheds are shown in appendix A-4.

Playing Fields: Baseball and Multi-field

Baseball field areas are based on RIGIS Open Space (1988) occurrence of baseball fields in the watershed and the area of regulation baseball field size according to Clarkson Collins, Narrragansett Town Planner. Multi-playing field areas are based on RIGIS Open Space occurrence of playing fields in the watershed and the standard size of a soccer field according to Clarkson Collins. Nitrate-nitrogen loading for baseball and multi-fields is 3.8 kg/N/capita/yr based on Gold et al. (1990) for fertilized home lawns because similar application rates were used by Gold et al. (2.3kg/93m^2/yr), as are used on a typical playing field in South Kingstown. Fertilizer application rates were obtained from the South Kingstown Department of Parks and Recreation (.45kg/93m^2/yr - low use and 1.8kg/93m^2/yr - high use, and Narragansett Parks and Recreation which uses 1.4 kg/93m^2/yr - 1.6kg/93/m^2/yr. Calculations for nitrogen loading from baseball and multi-playing fields for each of the salt pond watersheds are shown in appendix A-5 and A-6.

Atmospheric Deposition to Open Space and Directly on the Salt Ponds

A salt pond can receive atmospheric deposition both directly to its surface and indirectly from its watershed. The watershed can trap some of the fixed nitrogen in rainfall while the rest runs off into streams and to other water bodies. Nitrogen can be taken up or retained in varying degrees by croplands, forests, lawns, pastures, and commercial areas. It is difficult to measure how much nitrogen from atmospheric deposition is retained in the watershed and how much enters the salt ponds because of other sources of nitrogen (septic systems, agriculture fertilizers, home lawn fertilizers etc.) in the watershed. Moreover, there is natural nitrogen fixation in the watershed.

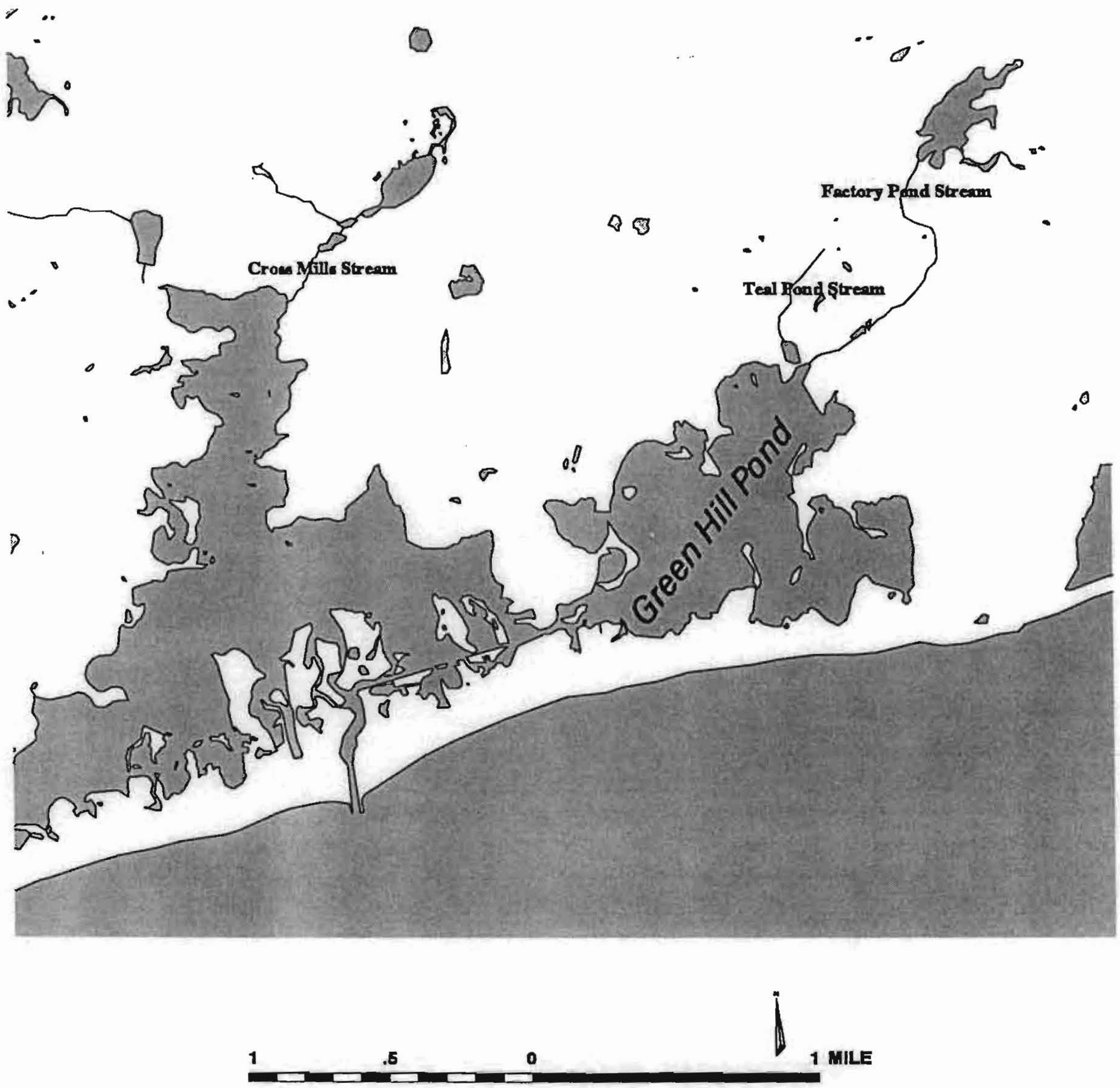
Nitrogen fixation for the salt pond watersheds in 1980 and 1994 is based on the estimates used by Fraher (1991). The salt pond GIS database from 1994-1995 was used to get the salt pond areas for the 1994 calculations. The 1988 RIGIS land-use database for areas of undeveloped land was used to calculate nitrogen loading from precipitation to groundwater. RIGIS undeveloped lands used in the nitrogen loading calculation include idle agriculture, deciduous forest, evergreen forest, miscellaneous deciduous forest, mixed evergreen forest, transitional and wetland areas, airports, railroads, waste disposal, power lines, vacant land, cemeteries, pasture, orchards, nurseries, confined feeding areas, brushland and mixed barren areas. The 1980 nitrogen loading areas for precipitation are based on the entire area of the watershed since data on undeveloped lands was not available. The volume of precipitation falling on the watershed in 1980-81 is from the URI Weather Station at the Greene Herb Gardner, Jr. Research Farm, Kingston, Rhode Island for 1980 - 1981. DIN concentration is from data collected and analyzed by Nixon et al. (1982). The volume of precipitation falling on the watershed in 1994-95 was calculated from the URI Weather Station at the Greene Herb Gardner, Jr. Research Farm, Kingston, Rhode Island for July 1994 - June 1995. Concentration of nitrogen in rainfall for 1994-95 is based on Fraher (1991). Fraher considered both wet deposition and direct dry deposition from nitric acid vapor using samples collected from Prudence Island. Dry deposition is the transport of atmospheric aerosols and gases to surfaces during periods of no precipitation (Fraher, 1991). Fraher used Gold et al. (1990) for his nitrogen loss factor to groundwater from atmospheric deposition. Results from Gold et al. (1990) show that concentrations of nitrate-N were below the detection limit of 0.2 mg/l in 90% of the soil-water percolate samples from unfertilized treatments. The calculation for nitrogen loading to groundwater from precipitation falling on undeveloped lands assumes that NH_4 is converted to NO_3. Calculations for each of the salt ponds are shown in appendix A-7 for undeveloped lands and in Appendix A-8 for direct deposition to the salt ponds.

Stream Discharge

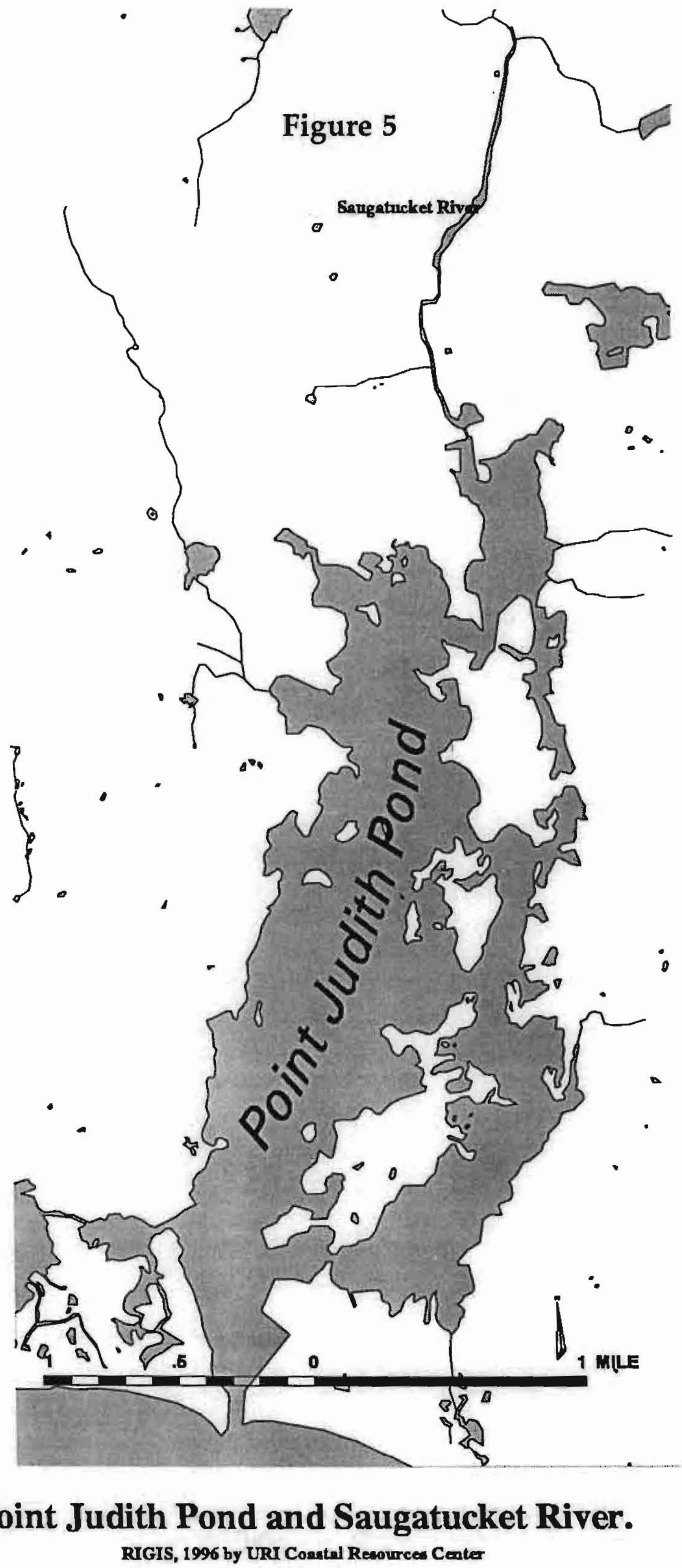
Measurement of DIN concentrations and stream flow for 1994-95 were made in the streams entering Ninigret and Green Hill Ponds (Figure 4), and the Saugatucket River which flows into Point Judith Pond (Figure 5). Cross Mills Stream flows into Ninigret Pond at Fort Neck Cove in the most northern part of the salt pond. Teal Pond Stream and Factory Pond Stream both flow into the northern part of Green Hill Pond. These streams and the Saugatucket River were measured for N flux in 1980-81 by the University of Rhode Island Graduate School of Oceanography (Nixon et al., 1982).

Eleven measurements of flow and nutrient concentration were taken between July 1994 and June 1995. Annual stream loading was not included in the total nitrogen loading budget for 1994-1995 because data were based on wet weather events only and there was no base flow sampling. Annual loading was not a major factor in 1981, though that was a relatively dry period. Stream runoff is from recharge and runoff that is isolated from the groundwater flow that is used in the coastal pond groundwater calculations. Cross Mills Stream and the Saugatucket River were both measured using a General Oceanic Model 2031C flow meter with a Model 2035 MKIII Flow meter readout in meters/second across a cross sectional area of the stream. A staff, placed in Cross Mills stream and on the Main Street bridge abutment for the Saugatucket River, was used to measure relative change in depth. The cross sectional area was measured to determine the volume of water flowing through at a particular stage; the area was marked off with a rope tied across the stream or river, and water depth was measured every 25 centimeters across the river or stream to determine the total volume of water at that particular staff height (Granger, Personal Communication, 1994).

Figure 4



Green Hill Pond and Factory Pond Stream and Teal Pond Stream.
Ninigret Pond and Cross Mills Stream.
RIGIS, 1996 by URI Coastal Resources Center



Point Judith Pond and Saugatucket River.

RIGIS, 1996 by URI Coastal Resources Center

Flow volume was calculated by adding the additional height related area to the base flow. Flow measurements were taken every 25 centimeters. The total discharge was calculated by multiplying the flow (m/s) at each measuring station (every 25cm) by the volume of water flowing through the station (the volume of water figured from the height of stream stage, and the area of each measuring station). The area of each measuring station was determined by drawing a scaled version of the cross-section and multiplying the width x length of the water column every 25cm. Samples were analyzed by Betty Buckley at URI/GSO for nitrate, nitrite, and ammonia using the QuikChem Method 11-107-04-1-B for Nitrate/Nitrite, Nitrite in Seawater; QuikChem Method 11-107-06-1-C for Ammonia in Seawater (Prokopy, 1992).

The Saugatucket River was measured at the Main Street Bridge in Wakefield. The flow measuring station was beneath the bridge and the water sampling station was just under the bridge closer to the shore. During low flow events access to the river was possible. However, during high flow events it was necessary to measure the flow from the bridge railing by lowering the flow meter impeller down on a weighted rope. Samples were still obtained from the side of the river where the flow was not as strong. The eleven storm events varied in strength and duration. Most samples and measurements were taken during a rainfall event.

Teal Pond Stream and Factory Pond Stream both discharge into Green Hill Pond. Teal Pond stream flow was measured at the culvert bridge on Matunuck School House Road with a V-notched weir. The weir was made of a metal plate with a 90 degree angle cut out for the V-notch. A staff was painted on the weir to measure the height of the water. The weir was placed in the stream bed with sand bags to direct the flow over the v-notch. A formula for calculating flow over a v-notched weir was used from the U.S. Geological Survey:

$$(Q = \frac{Ch^5}{2})$$

where Q is the discharge, h is the static head, and C is the coefficient of discharge (Carter and Davidian, 1968). The coefficient of discharge is 2.47 cubic feet per second, which represents the volumetric flow of water over the v-notched weir. The static head was determined by comparing the staff on the weir with the upstream staff. The upstream staff is used to determine how much head is on the weir. The upstream staff reading was used to solve the equation for flow.

Factory Pond Stream was measured at the culvert which passes under Teal Road in Wakefield (off Matunuck School House Road). There are actually two culverts at this location. One was blocked off with a circular plywood cover. Once the water level stabilized in the other culvert (about five minutes), the flow meter used for Cross Mills Stream and the Saugatucket River was used to measure flow through the culvert. The area of the culvert was measured and a staff was used to determine the height of the water in the culvert. The volume of water flowing though the culvert was calculated by drawing a scaled version of the culvert and determining the area from the scaled drawing.

Stream and river water samples were collected in two 500 ml polyethylene bottles through a sterile syringe with a filter. The samples were kept on ice in a dark cooler until reaching the URI Graduate School of Oceanography Horn Laboratory. The samples were frozen until analyzed[6]

[6]All water samples related to this thesis were run in the Horn Lab of the University of Rhode Island, Graduate School of Oceanography by Betty Buckley as part of a study conducted by the URI Coastal Resources Center with funding from the Rhode Island Sea Grant Program, and the Rhode Island Coastal Resources Management Council through a section 309 grant under the Coastal Zone Management Act.

using the QuikChem Method 11-107-04-1-B for Nitrate/Nitrite, Nitrite in Seawater; QuikChem Method 11-107-06-1-C for Ammonia in Seawater (Prokopy, 1992). The results of the concentration analysis were given for nitrate-N (NO_3), nitrite-N (NO_2), and ammonia-N (NH_3).

To calculate DIN flux to the Ponds, the concentration was multiplied by the discharge for the particular sample date. All concentrations, flow measurements, and loading results for each sample date are provided in Appendix B for each stream. The average yearly fluxes and discharges for the streams were calcualted by averaging the discharge and flux over the eleven storm events and multiplying this average by 365 days to get a yearly flow and flux. The total annual discharges (l/yr) and flux (kg/yr) for 1980-81 and 1994-95, for each stream and the Saugatucket River are provided in Table 6. The total DIN load to Point Judith Pond from the Saugatucket River was 27 metric tons per year. Factory Pond Stream and Teal Pond Stream together had a total DIN load of 3.3 metric tons per year into Green Hill Pond. Cross Mills Stream had a total DIN load of 1.1 metric tons per year. These values overestimate the annual water and nitrogen fluxes because of the sampling bias toward higher dishcarges during storm events. Instead, I compared flux and flow for each of the streams in Figure 6.

Table 6. Annual Discharge (m^3/yr) and Flux (kg/N/yr) for 1994-95 for Cross Mills Stream, Factory Pond Stream, Teal Pond Stream, and the Saugatucket River.

Stream/River	Annual Discharge (m^3/yr) 1994-95	Annual Flux (kg/yr) 1994-95	Annual Discharge (l/yr) 1980-81	Annual Flux (kg/yr) 1980-81
Saugatucket River	42×10^6	27.0×10^3	9.5×10^9	7.3×10^3
Factory Pond Stream	2.5×10^6	0.6×10^3	1.37×10^9	$.2 \times 10^3$
Teal Pond Stream	2.3×10^6	2.8×10^3	1.95×10^9	1.7×10^3
Cross Mills Stream	6.7×10^6	1.1×10^3	2.57×10^9	$.2 \times 10^3$

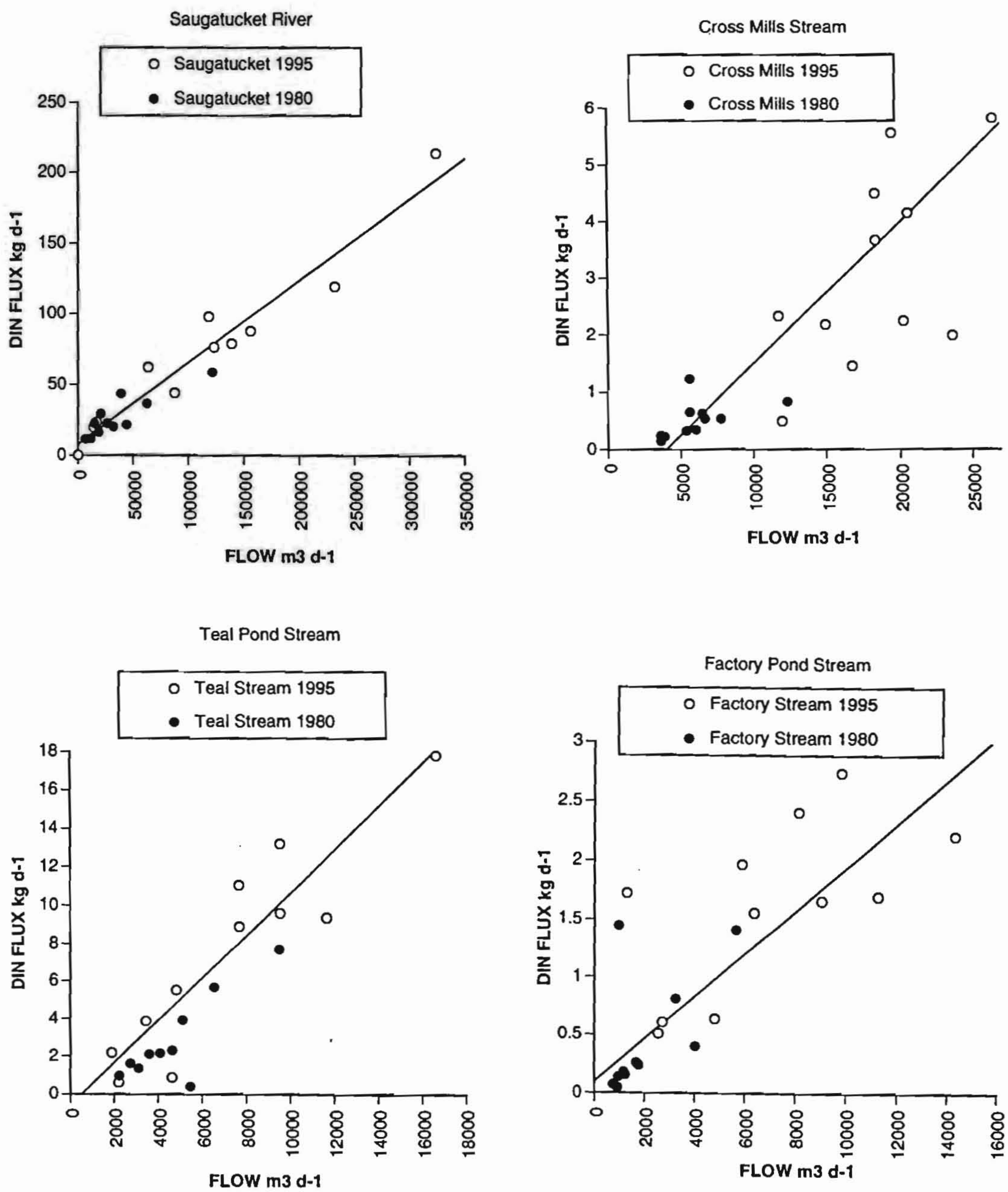
Concentration averages between 1980-81 and 1994-95 are shown in Table 7. Although the portion of DIN in nitrate is similar between the two sample years, the amount of NH_3 in DIN has increased.

Table 7. Daily average concentrations of NO_3 and NH_3 for 1980-81 and 1994-95 in the Saugatucket, Teal Pond, Factory Pond and Cross Mills Streams (mg/l).

Stream	1980-81 Avg. NO_3	1994-95 Avg. NO_3	1980-81 Avg. NH_3	1994-95 Avg. NH_3
Saugatucket	0.82	0.54	0.18	0.27
Teal	0.87	1.1	0.02	0.02
Factory	0.14	0.30	0.02	0.02
Cross Mills	0.06	0.10	0.02	0.05

Figure 6

DIN Flux v. Flow for the Saugatucket River, Cross Mills Stream, Teal Pond Stream and Factory Pond Stream.



Chapter 4

Interpretation of Results: Calculated Nitrogen Loading Budget

Groundwater Budget

Discussion of the calculations of nitrogen loading to groundwater refers to the tables in Appendix C, which indicate nitrogen loading from the different land-uses in each watershed for 1981, 1992 and buildout. The buildout column represents the loading expected when the watersheds are completely developed according to current zoning regulations in each of the towns. The buildout budget is based on a land-use buildout compiled by RIGIS (1995) and the town zoning maps. There are differences in the loading estimates for 1992 and buildout for undeveloped lands and multi-playing fields. Undeveloped lands are federal, state, and local areas which are currently in open space easement but are not counted as undeveloped in the buildout analysis if they fall under a zoning designation according to town regulations. These lands are considered buildable because they are designated by the towns as zoned for development. Consequently, these lands are included in the total nitrogen loading calculations at buildout. Large portions of these acres are in agriculture. Other components of undeveloped acres are part of the Farm, Forest, and Open Space Act, which allows land to be assessed at its current use-value in order to encourage the maintenance of Rhode Island's productive agriculture and forest land. Landowners in the program must agree not to develop or subdivide their land for a minimum of 15 years. In return for this commitment, the land is taxed at the lower "current use" rate. There is a monetary penalty for early withdrawal or disqualification from the program (Town of Narragansett, 1994). The buildout analysis does not account for existing undeveloped lots which are substandard (less than 2 acres for residential development), and may be grandfathered or permitted through a variance. Although some of these variances do not fall within the watersheds of the salt ponds, there will undoubtedly lots which are developed at less than 2 acres before the watersheds are fully developed.

The largest contribution of nitrogen to groundwater in 1981 and 1992 in Point Judith, Potter, Trustom, Green Hill and Ninigret watersheds is from septic systems. The largest contribution of nitrogen to groundwater in 1981 in Cards Pond watershed was agricultural land-use, which accounted for 3/4 of the 1981 nitrogen budget. Residential contributions dominate all of the watershed nitrogen budgets in 1992 and are responsible for the greatest budget increases in input between 1981 and 1992.

Understanding population changes is essential to forecasting the potential impacts of nitrogen loading from residential sources. The south shore, along which the salt ponds are located, has changed from a summer cottage to a year-round community. Many people retire there, or live there, and commute to Providence, or live and work in the region. As a result, the south shore towns have had to consider growth management tools in planning for zoning regulations, open space, and public facilities (Ray Nickerson, Town of South Kingstown, personal communication, 1995).

Nitrogen loading from undeveloped lands increased between 1981 and 1992 in all of the watersheds. Although dry deposition was not measured in 1981, there was an increase in the concentration of NO_3, NO_2 and NH_3 in wet deposition from 0.49 mg/N/l to 0.65 mg/N/l. Based on the data used in this study it is not evident if this increase is a trend or an anomaly of the two data years studied. Also, the increase could be attributed to different methods of measurements in 1980 and 1990. Since the area of undeveloped land is assumed to be the same for 1981 and 1992,[7] the increase in nitrogen loading is due entirely to an increase in atmospheric deposition. The 1992 loading also includes the nitrogen flux from dry deposition. Dry deposition accounts for 0.39 mg/l of the 1.04 mg/l total deposition in 1992. The increase in atmospheric wet deposition of nitrogen is contrary to the United States Environmental Protection Agency's 1991 report, "National Air Quality and Emissions Trends," which states that NOx in the atmosphere has decreased by 25% between 1982-1991. The Clean Air Act as amended in 1990 (P.L. 101-549) regulated NOx emissions in states which failed to meet the national ambient air quality standards. The decrease in NOx is attributed to improved automobile technology, despite increases in vehicle traffic (U.S. Department of Transportation and EPA, 1993). Based on the data existing for southern Rhode Island, it does not seem that there has been a decrease in NOx emissions; or, if there has been a decrease, it has not affected the concentration of nitrate-nitrogen in wet deposition. More than 2.9 million metric tons of nitrogen are deposited in the United States each year from the atmosphere (Sisterson, D.L., 1990 as cited in Puckett, 1995); of these, the northeastern states receive the most (Puckett, 1995).

Agricultural land-uses have changed considerably in the SPR between 1981 and 1995. Quantifying this change was difficult because of the lack of accurate agricultural acreage for some watersheds. Data in the loading budget are based on personal communications and the 1988 RIGIS land-use data for present day agriculture (In Cards, Potter and Point Judith Pond watersheds). The 1981 data are based on the 1988 RIGIS land-use database. The 1988 data were used to calculate the budget because reliable estimates did not exist for

[7]Since there were not better estimates for undeveloped lands, acreage is based on the 1988 RIGIS land-use database for 1981 and 1992.

row-crop agriculture in 1981 for any of the salt pond watersheds; actual acreage for row crops in 1992 could only be obtained for Cards, Potter and Point Judith Ponds by contacting the farmers personally.

Obtaining accurate numbers for areas of land in agriculture, the type of agriculture (hay, pasture, row crops etc.), fertilizer application rates and fertilizer management (i.e. cover crops, soil testing) is important because different agricultural practices and crop types impact the amount of nitrogen loss to groundwater. Manure fertilized corn was the only type of crop considered because both farmers interviewed had either corn or hayfields.

The biggest difference in the agriculture loading is in Cards Pond watershed, where the loading went from 17103 kg/yr in 1981 to 4869 kg/yr in 1992. The difference in loading had a dramatic effect on the calculated nitrogen concentration in groundwater, decreasing from 10 mg/l to 5 mg/l. The Cards Pond example is important because it emphasizes both the enormous contribution agriculture can have to nitrogen loading to groundwater, and it also shows the changes in land-use in some parts of the SPR.

Calculated Concentrations of Nitrogen in Groundwater

The nitrogen loading budgets for each salt pond watershed indicate which land-uses have the greatest impact on groundwater concentrations of nitrogen in 1981, 1992, and at buildout. The groundwater volumes from Grace and Kelley (1981), and the total nitrogen load to groundwater, were used to calculate the concentration of nitrogen in groundwater for 1981, 1992 and buildout.[8] These concentrations appear at the bottom of each nitrogen

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[8]Groundwater concentration of nitrogen was calculated as follows: nitrogen loading kg/yr / groundwater volume m^3. e.g. (23118 kg/yr *1000000mg/1kg)/25270000m^3*1000l = .91mg/l.

loading budget for groundwater in mg/l (Appendix C). In order to estimate changes in groundwater between 1981 and 1992, the U.S. Geological Survey (USGS) Water Table Elevations data were collected from 1980 through 1994. This data appears in Appendix D. Two USGS wells, one located in Westerly (Dunn's Corner - Well WEW522), and the other in Charlestown (Ninigret Park - Well CHW18), indicate that groundwater elevations increased between 1981 and 1994. Well WEW522 increased 0.15 meters and well CHW18 increased 0.61 meters. Although there were changes in the groundwater elevations, the calculated groundwater concentration of nitrogen in this research is based on the 1981 groundwater volumes from Grace and Kelley. Consequently, these calculations may or may not be reflecting the actual groundwater volume which is entering the salt ponds. It would be useful to have a hydrologist re-examine the groundwater situation in the SPR, and adjust the groundwater concentrations calculated here based on a more recent hydrologic analysis. The total loading for different nitrogen sources in each watershed reflects the changes in land-use between 1980 and 1995.

Cards Pond

Since there was little increase in the number of housing units in the watershed between 1981 and 1992, the septic contribution to the nitrogen loading budget increased only 232 kg. The biggest change between the two sample years was a 28% decrease in agriculture loading. This reduction dramatically reduced the calculated groundwater concentration of nitrogen from 10.2 mg/l in 1981 to 4.8 mg/l in 1992 (Appendix C). However, given the current zoning, this watershed's development potential to the extent that concentrations of nitrogen in groundwater may increase by 4.3 mg/l at buildout. In the case of Card's Pond, agriculture is no longer dominating the nitrogen loading budget because fields are now being converted to residential housing. The consequences of this land-use change, assuming consistent zoning regulations, will be an increase in nitrogen loading to Cards Pond at buildout. The possibility of nitrogen loading increases to Cards Pond from residential land-use provides an opportunity for the Town of South Kingstown, conservation organizations, and the R.I. Coastal Resources Management Council to reduce the potential number of homes at buildout by conservation easements, and tax breaks for land conservation.

Trustom Pond

Land-use in Trustom Pond watershed is similar to the Cards Pond watershed except that a U.S. Department of Interior, U.S. Fish and Wildlife National Wildlife Refuge borders to the north and east of the salt pond (U.S. Fish and Wildlife Service, 1991). Nitrogen loading from residential development doubled between 1981 and 1992, and at buildout the increase in residential development will result in a calculated nitrogen increase in groundwater from 3.3 mg/l to 4.1 mg/l. Agriculture decreased in the watershed, resulting in the change in calculated groundwater concentration from 5.4 mg/l in 1981 to 3.3 mg/l in 1992.

The land-use changes in both Trustom and Cards Pond watersheds between 1981 and 1992 reduced the amount of nitrogen loading into each Pond. However, the calculated groundwater concentration is still 4.8 mg/l for Cards and 3.3 mg/l for Trustom Pond watershed in 1992. Although the loading decreased time, there is still an opportunity for further reduction by using best management practices with agricultural land-use, and decreasing the density of future development.

Point Judith

The decrease in agriculture between 1981 and 1992 is more than compensated for by an increase in nitrogen loading from residential land-use of 7326 kg. This increase does not have a big affect on the calculated groundwater concentration which increased from .91 to 1.1 mg/l. The increase in residential development at buildout will impact the groundwater concentration of nitrogen, raising the calculated value from 1.1 mg/l to 1.7 mg/l. The buildout for Point Judith Pond watershed does keep the calculated groundwater concentration at a level which is safe for public drinking water.

Potter

Potter Pond watershed had a tremendous decrease in nitrogen loading from agricultural land-use between 1981 and 1992. The reduction in loading resulted in a decrease in the calculated groundwater concentration of nitrogen from 5.7 mg/l to 3.4 mg/l. The loading from residential land-use also decreased because the median number of people per house decreased from 2.4 to 2.32 (between 1980 and 1990) (U.S. Census Bureau, 1980; U.S. Census Bureau, 1990). Looking at the increase in dwelling units proposed for buildout, there is the potential for 1286 more houses in the watershed, which would increase the total loading to Potter Pond from 3.4 mg/l to 5.9 mg/l. This increase could bring groundwater concentrations of nitrogen back to 1981 levels.

Green Hill Pond

Nitrogen loading to groundwater in the Green Hill Pond watershed has increased because zoning regulations continue to allow more residential development. Agricultural loading remained the same between 1981 and 1992, because no current data was available and loading from undeveloped lands only increased by a 475 kg/yr. Consequently, residential development alone is responsible for increasing the calculated groundwater concentration of nitrogen from 3.1 mg/l to 3.8 mg/l.

Ninigret

Ninigret Pond watershed had the smallest increase in calculated groundwater concentration of nitrogen 1981 and 1994. Furthermore, the concentration will remain the same at buildout, if current day zoning regulations are maintained.

Residential sources of nitrogen in watersheds of the salt ponds are adding incrementally to the loading budget, and will continue to do so because zoning regulations and land-use planning decisions made by the SPR towns are increasing the number of septic systems, fertilizers and domestic pets in the watershed. The contribution of residential nitrogen sources is an obvious target for nitrogen reduction. The 1981 SAMP attempted to control nitrogen increases through zoning regulations as a means to control development. Although the SAMP increased the minimum acreage for a residential lot to two acres in the salt pond watersheds, these changes only applied to unplatted lands. Many lots were pre-platted at the time the SAMP recommendations were implemented, and consequently these lots were grandfathered for development. The changes between 1981 and 1992 in the salt pond watersheds indicate that septic systems, domestic pets and lawn fertilizers are increasing the amount of groundwater nitrogen loading to levels which could be of concern for human and ecosystem health.

Stream Flux and Discharge

Since annual flux to the salt ponds was not used to compare changes between 1980 and 1995, the focus of this discussion is on the changes in stream concentration and flux versus flow in each of the streams.

The Saugatucket River average concentration of NO_3 decreased in 1994-95, but the average concentration of NH_3 increased by 0.09 mg/l. NH_3 is a major component of the dissolved nitrogen found in sewage effluent and is also present in rain (Mackenthun and Taft, 1965). It is possible that average concentrations of ammonia were higher because sampling was completed in wet weather events. Higher stream flows would mean shorter residence time of water in the streams and consequently less time for nitrifiers to convert NH_3 to NO_3. There also might be failing septic systems which are causing point sources of effluent to the Saugatucket River. Since there are areas of Wakefield which are unsewered, it is very possible that there may be a problem with failing systems. The Saugatucket River sampling station was located at the Main Street Bridge in Wakefield, R.I., which is a highly impervious commercial area with high density residential and commercial development.

Teal Pond Stream average NO_3 concentration increased 0.23 mg/l between 1980 and 1995. Factory Pond Stream average NO_3 concentration increased 0.16 mg/l between 1980 and 1995. Teal Pond Stream and Factory Pond Stream average NH_3 concentrations remained the same. Cross Mills Stream average NO_3 concentration increased 0.04 mg/l between 1980 and 1995 and average NH_3 concentration increased .03 mg/l.

There may be several causes for increases in stream and river nitrogen concentrations. Atmospheric deposition of nitrogen to the streams may be impacting the total flux of nitrogen to the salt ponds; streams could be transmitting nitrogen from upper portions of the watershed to the salt ponds, and increases in development in the watersheds could cause an increase in nitrogen in the streams. Increased amounts of run-off probably added to the increase in discharge, because the amount of rainfall in 1980-81 was 0.86 meters compared to 1.19 meters in 1994-95. The concentration of DIN in rainfall increased from 0.49 mg/l wet deposition in 1980-81 to 0.65 mg/l wet deposition (1.04 wet and dry deposition) in 1994-95.

Comparing flux versus flow in all of the streams in Figure 5, on page 74, flux is consistently higher with increased discharge. There is no sign of increases of nitrogen within the watersheds of the Saugatuket River or Teal Pond Stream where the flux appears to be a result of flow, and the R^2 indicates a good relationship between the data points. Cross Mills and Factory Stream regressions do not indicate a clear relationship between the data points and the data are not conclusive.

Total Calculated Nitrogen Loading Budget

When the calculated groundwater budget is considered together with contributions from precipitation directly on the ponds, groundwater is the dominating source of nitrogen. Since stream discharge is not based on based flow, stream flux was not included in the total budget. Atmospheric deposition increases are due to an increase in the amount of rainfall between 1981 (1.19 m) and 1992 0.86 m), an increase in the concentration of nitrogen in wet deposition, and the inclusion of dry deposition to the 1992 budget.

Atmospheric Deposition

Nitrogen in precipitation has increased by 0.16 mg/l since 1980-81 for wet deposition. Based on data from Fraher (1991), 1992 atmospheric deposition (wet and dry) accounts for 2% - 21%. As a measure of comparison for the salt ponds, wet and dry deposition accounts for approximately 4% of the input of dissolved inorganic nitrogen budget to Narragansett Bay, considering only the direct input into the bay (Fraher, 1991). The Environmental Defense Fund, in an assessment of the role of acid rain in the Chesapeake Bay, determined that direct atmospheric deposition accounts for 9% of the total nitrogen loading budget for the Bay (Fisher et al., 1988). Fraher (1991) noted the Chesapeake Bay estimate was higher than his because the Environmental Defense Fund assumed that wet deposition is equal to dry, whereas Fraher's estimates found dry to be slightly less. Since the salt pond nutrient budget in 1981 did not consider dry deposition, only the 1992 numbers can be used to compare to the Environmental Defense Fund study and Fraher's thesis. The salt pond direct atmospheric input of nitrogen accounts for 21% of the total budget (17% more than in Narragansett Bay, and 12% more than in the Chesapeake Bay). Atmospheric sources are a greater percentage in the salt ponds because the watersheds are small in comparison to the size of the Ponds; whereas, in receiving waters like the Chesapeake and Narragansett Bay, the watersheds are large in comparison to the area of the bay. Paerl (1993) notes that the proportionality of watershed to water body areas and volumes is an important factor when considering the role of atmospheric deposition of nitrogen in coastal eutrophication. Atmospheric deposition of nitrogen poses some interesting policy implications because communities trying to control nutrient fluxes within the landscape are reliant on federal regulations of air quality emissions to control nitrous oxides.

Puckett, in a national watershed-based analysis of nitrogen and phosphorus sources for the U.S. Geological Survey, National Water Quality

Assessment Program, noted that there was a pronounced west-east trend of increasing nitrogen inputs, with the largest inputs in northeastern watersheds (Puckett, 1995). This trend makes sense considering more than 2.9 million metric tons of nitrogen are deposited in the United States each year from the atmosphere, primarily in the northeastern states (Sisterson, 1990, as cited in Puckett, 1995).

Chapter 5

Methods and Results
Empirical Method: Measurement of DIN in Groundwater

Methods

Groundwater Well Concentrations

The empirical method has two parts: the measurement of nitrogen in groundwater and a comparison to the calculated method; and, a statistical analysis of the nitrogen concentrations to test for significant differences between the two years 1980 and 1994.

The 1982 Statewide Planning Report on nitrogen inputs to the Rhode Island salt ponds included sampling and analysis of groundwater concentrations of nitrogen in an attempt to relate increasing nitrogen loading to the increasing density of development in the salt pond watersheds (Nixon et al., 1982). These data were used to support low density development recommendations to the respective towns. Using information from Nixon et al., 1982, 111 groundwater samples were obtained from private wells within the Point Judith, Potter, Cards, Trustom, Green Hill and Ninigret Pond watersheds. The names and addresses of each homeowner were filed at the Graduate School of Oceanography (Granger, personal communication, 1994). These references were used to relocate the wells again. Supporting data were obtained from the homeowners, if possible. Questions asked included the type, age, and depth of the well. In those instances where the homeowner had changed from a private well to public water a portable well pump was used to take the sample. Most of the wells were concrete casement, and a few were rock encased. A portable generator was used to operate the Grunfos 25SO5-3 1/2 horsepower pump weighing 26 lbs and capable of pumping over 70 gallons a minute. The pump was lowered to the bottom of the well and then raised a foot to allow room for water intake. Water was pumped from the well with a garden hose for ten-fifteen minutes to allow the well to recharge. Samples were taken in 500ml polyethylene bottles which were than placed in a cooler on ice. Samples were then frozen at the URI Graduate School of Oceanography until analyzed. All samples were analyzed using the same procedures as the stream samples. Well water concentrations, well depth, well age, well type, sample date, and well use, are found in Appendix H, and are identified by well number, and salt pond watershed.

Test for Significant Differences between 1980 and 1994

In order to determine if there are significant differences between each year of samples, the Paired Student t test was performed (Dowdy and Wearden, 1983). To perform this test, first the differences between the paired sets of data were found (Yd). This means the difference between the 1980 and 1994 concentrations for each of the 111 samples was determined. The sum of these differences was divided by the total number of samples (111). Secondly, the sum of the differences between the paired samples was squared (Sd^2) and divided by the total number of samples. This number was then subtracted from the sum of the differences between the paired samples and divided by the number of samples minus 1. The actual formula to test this hypothesis is written:

$$Yd = \frac{\Sigma Yd}{n}$$

$$Sd^2 = \frac{\Sigma Yd^2 - \frac{\Sigma Yd^2}{n}}{n - 1}$$

Where:
$Yd=$ the difference between the matched pairs (1981 - 1994 concentrations)
$\Sigma Yd=$ the sum of the difference between the matched pairs
$n=$ the number of samples
$Sd^2=$ the squared difference between the matched pairs

Nitrogen Loading to the Salt Ponds From Groundwater Measurements

Total groundwater volume for each Pond was taken from Grace and Kelley (1981). To determine the total nitrogen load from groundwater to each salt pond it was assumed that the groundwater volume in each watershed remained the same between 1980 and 1994 (Grace and Kelley, 1981), that all of the groundwater coming from the watershed flows into the salt ponds, and the average of the nitrogen concentration measured in each watershed represent the nitrogen concentration of the groundwater flowing into the salt pond. The loading calculations were made by determining the average groundwater nitrate concentration for each watershed and then multiplying by the volume of groundwater entering the pond.

Results

Groundwater Well Concentrations

Dissolved inorganic nitrogen (NH_3 and NO_3) concentrations from 1980 and 1994 are shown in Appendix H. The 1994 nitrate concentrations in all of the wells ranged from 0-9.85 mg/l of NO_3 with an average concentration of 2.14 mg/l of NO_3. This compares to the 1980 range of 0- 19.10 mg/l of NO_3 and average concentration of 3.02 mg/l. The 1980 and 1994 average NO_3 concentrations (mg/l) are shown in Table 8.[9]

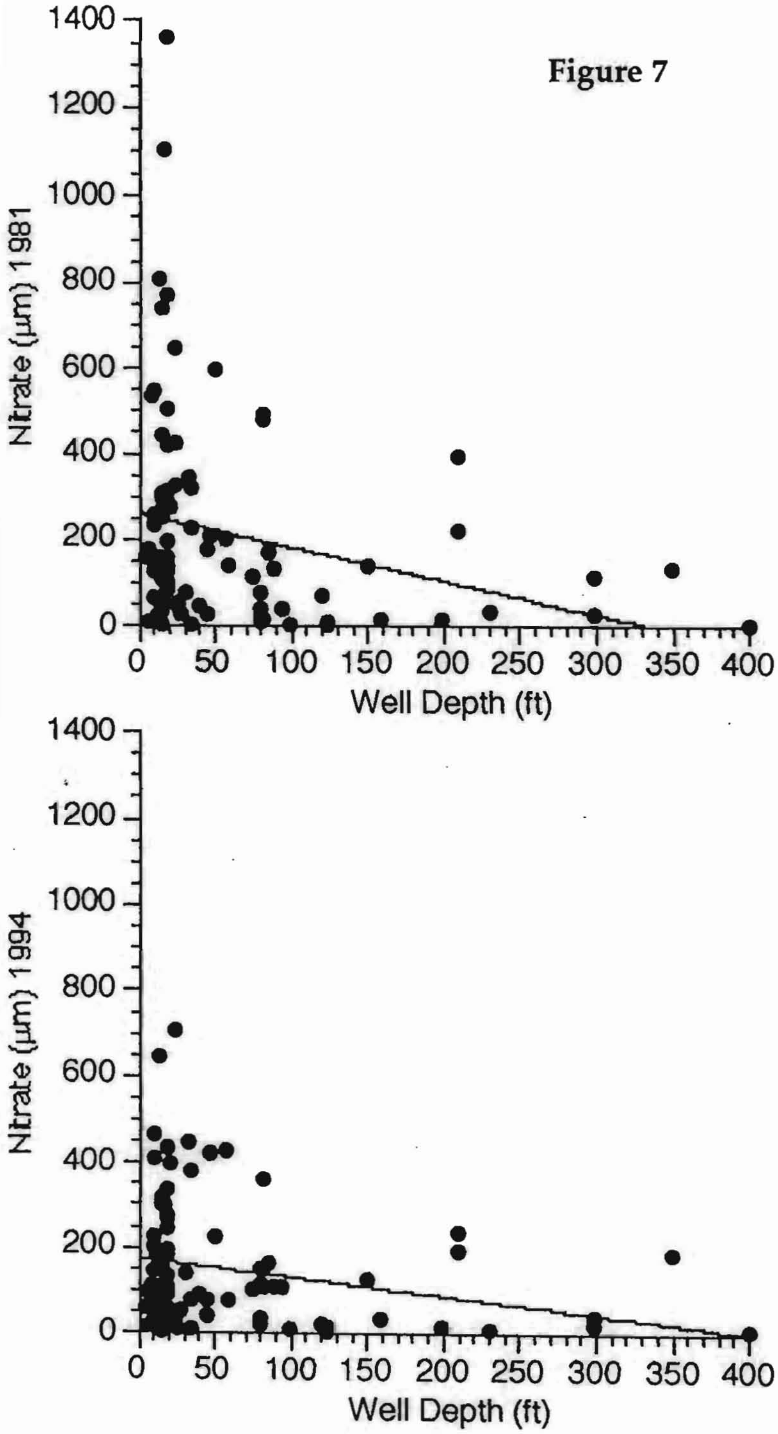
[9]Dissolved inorganic nitrogen, NH_3, and NO_3 concentrations from 1980 and 1994 are shown in appendix J.

Table 8. 1980 and 1994 average nitrogen well water concentration (mg/l). Based on 111 well samples.

Watershed	Mean NO_3 1980	Mean NO_3 1994
Point Judith	3.38	2.39
Potter	2.52	2.11
Cards	2.08	3.72
Trustom	2.14	1.62
Green Hill	3.61	2.82
Ninigret	1.68	1.46

Well depth and concentration were plotted with well depth as the independent variable and concentration the dependent variable. This plot indicates that higher concentrations of nitrate are consistent with shallow wells (Figure 7). The well depth/concentration result is the same as a recent analysis compiled under the joint Farm Bureau Federation/Heidelberg College Cooperative Private Well Testing Program, which compared the results of data collected from 34,759 wells in Ohio, Indiana, Illinois, Kentucky, and West Virginia. The Water Quality Laboratory of Heidelberg College found that nitrate concentrations were significantly higher in older or shallow wells (Terrene Institute, 1995).

Figure 7



Nitrogen Loading to the Salt Ponds From Groundwater Measurements

Although the present research did not include an analysis of the changes in hydrology in the salt pond watersheds, United States Geological Survey water table elevation data were used from two wells in the region to estimate changes in water table elevations. One well was located in the Ninigret Pond watershed (Well CHW18) and one in Quonochontaug Pond watershed (Well WEW522). Water table elevations for 1980-81, 1991-92, 1992-93 and 1993-94 are shown in Appendix D. The difference between 1980 and 1994 for the Quonochontaug Pond well is 0.15 meters below land surface datum, and for the Ninigret well, 6.6 meters below land surface datum. Differences in well water depth reflect the greater amount of rainfall for 1994-95 (13.83 meters) versus 1980-81 (10.30 meters). The normal rainfall for Kingston, RI is 15.22 meters, so even 1994-95 had less rainfall than normal (URI Weather Station, 1980, 1981, 1994, 1995). Although the increase in volume of groundwater flowing to the salt ponds cannot be calculated based on the water table elevations alone, the USGS data do indicate that Grace and Kelley's (1981) groundwater flow estimates may be conservative. Because the volume of water affects the total calculated loading, a hydrologist should study the region as a whole to better understand the changes in groundwater flowing into the salt ponds. However, since the same groundwater volume is being used for the calculated and measured methods of computing the nitrogen load (and for both 1980 and 1994), any changes in nitrogen loading will be a result of a change in the calculated and measured nitrogen calculations.

Groundwater flow estimates for each watershed were multiplied by the average measured DIN concentrations to obtain the nitrogen loading estimate to the salt ponds. Table 9 shows the groundwater flow volumes, the average measured DIN concentrations, and the loading to the salt ponds from the measured data. This table compares the calculated loading from measured groundwater concentrations in 1980 and 1994, with the calculated loading based on literature values in 1980 and 1994. Finally, Table 10 shows the measured groundwater concentration and the calculated groundwater concentration for 1980-81, 1994-95, and at full development of the watershed.

Table 9. Groundwater Flow (1981), average measured and calculated NO_3 concentrations, and the resulting load of NO_3 to the salt ponds for 1994.

Watershed	Groundwater Volume (m^3/yr)[1]	Calculated DIN (mg/l) (1994)[2]	Measured DIN (mg/l) (1994)[3]	Calculated Loading (kg/yr) (1994)[4]	Measured Loading (kg/yr) (1994)[5]
Point Judith	25270000	1.1	2.4	28333	50540
Potter	5010000	3.4	2.1	16999	10020
Cards	2160000	4.8	3.7	10415	8640
Trustom	1100000	3.3	1.6	3600	2200
Green Hill	6820000	3.8	2.8	25635	20460
Ninigret	14980000	2.0	1.5	29595	14980

[1] Grace and Kelley, 1981
[2] (kg/yr X 1000000 mg/1kg) /(Groundwater Volume (m^3) X 1000l/1m^3) = DIN mg/l
[3] 111 samples, Ernst et al., in prep.
[4] Based on groundwater volume from Grace and Kelley, 1981; literature values from Gold et al., 1990; the Long Island Sound Study (Nassau-Suffolk Regional Planning Board, 1978); RIGIS, 1996; and personal communications.
[5] mg/l X .000001kg/1mg/l X (Groundwater Volume (m3) X 1000l/1m^3)

Table 10. 1980-81, 1994-95 and Full Development (Buildout). Measured and calculated groundwater DIN concentrations (mg/l).

Watershed	1981 Measured NO_3 Concentration (mg/l)[1]	1981 Calculated DIN Concentration (mg/l)[2]	1994 Measured DIN Concentration (mg/l)[3]	1994 Calculated DIN Concentration (mg/l)[4]	Buildout DIN Concentration (mg/l)[5]
Point Judith	3.4	.91	2.4	1.1	1.7
Potter	2.5	5.7	2.1	3.4	5.9
Cards	2.1	10.2	3.7	4.8	9.1
Trustom	2.1	5.4	1.6	3.3	4.1
Green Hill	3.6	3.1	2.8	3.8	4.7
Ninigret	1.7	1.5	1.5	2.0	2.3

1 Based on 111 samples, Nixon et al., 1982

2 Based on groundwater volume from Grace and Kelley, 1981 and literature values from the Long Island Sound Study (Nassau-Suffolk Regional Planning Board, 1978), as presented in Nixon et al., 1982.

3 Based on 111 samples, Ernst et al, in prep.

4 Based on groundwater volume from Grace and Kelley, 1981; literature values from Gold et al., 1990; the Long Island Sound Study (Nassau-Suffolk Regional Planning Board, 1978); RIGIS, 1988; and personal communications.

5 Based on groundwater volume from Grace and Kelley, 1981; literature values from Gold et al., 1990; the Long Island Sound Study (Nassau-Suffolk Regional Planning Board, 1978); RIGIS, 1988 and 1995; and personal communications.

Test for Significant Differences between 1980 and 1994

The two data sets, 1980 and 1994, combining 111 samples, appear in Appendix E. The data sets were first tested using the statistical analysis software Systat to determine if the samples were normally distributed. Summary statistics are shown in Table 11. Although the standard deviation is greater than the mean of the 1981 sample distribution, a calculation of the skewness shows that the data set is only moderately skewed at a value of 0.8 (0.8 falls between 0 and 1, which is typical of a moderately skewed distribution (West, 1994)). Consequently, the 1981 data set was not normalized. In 1994, the standard deviation of 149.26 is less than the mean of 151.93, which suggests that the sample set is normally distributed. Skewness for 1994 is 0.99, corroborating a moderately skewed distribution.

Table 11. Summary Statistics of well water concentrations of NO_3 from 111 wells, 1980-1994.

Summary Statistic	**1980** NO_3	**1994** NO_3
Mean	213.14	151.93
Median	150.0	102.8
Standard Deviation	235.36	149.3
Skewness	0.8	0.99

The Paired Student t Test was calculated for all six of the salt ponds together and each watershed individually. The null hypothesis for the one tailed test is Ho: $\mu d = 0$ and Hr: $\mu d \neq 0$, meaning that the hypothesis is testing if the difference between the two data sets is statistically significant with an alpha level of 0.05 (two tailed). The test statistic was also tested for a one tailed test to determine the direction of the differences between the samples (1980 and 1994). The computation of Yd and Sd^2 is shown in Appendix F for the six watersheds together (Appendix F-1) and each individually (Appendix F-2 through F-7), where Yd equals the difference between the 1980 and 1994 DIN concentrations, and Sd^2 equals the square of the difference between the 1980 and 1994 NO_3 concentrations. The sum of the differences(ΣSd) and the sum of the squared differences (ΣSd^2), are shown at the bottom of each appendix page. Following are the calculations for the Paired Student t test, and the test statistic for all of the watersheds together and each individually:

Six watersheds together

The six salt pond watersheds were considered together to see if the samples in the whole region were significantly different between the two years 1980 and 1994. The following calculations test 111 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{Yd}{n} = \frac{6997}{111} = 63$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$Sd^2 = \frac{4415613 - \frac{(6997^2)}{111}}{110} =$$

$$Sd^2 = \frac{4415613 - 44106}{110} = \mathbf{36132.2}$$

Where

Yd	=	the difference between the matched pairs (1981 - 1994 concentrations)
ΣYd	=	the sum of the difference between the matched pairs
n	=	the number of samples
Sd^2	=	the squared difference between the matched pairs

Inserting the values into the paired Student t test model we get:

Test Statistic:

$$t = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$t = \frac{63 - 0}{\sqrt{\frac{36132.2}{111}}} = \frac{63}{18} = \mathbf{3.5}$$

With a confidence level of 0.05 for a two tailed test and 110 degrees of freedom, the level of significance is 1.98. Since t> 1.98 the paired test indicates that the nitrogen concentrations in groundwater within the watersheds of the six Ponds did significantly change between 1980 and 1994 (alpha .05). Since the Σ of Yd is positive, it is assumed that the 1994 samples are significantly less than the 1980 samples. The one tailed test, with a confidence level of .05

and 110 degrees of freedom, has a level of significance of 1.658, which is also less than the tabled value of 3.5. Therefore, the one tailed test is also significant. The one tailed test is also significant at the 0.0005 confidence level, and the two tailed is significant to the 0.001 confidence interval.

Point Judith Pond

The following calculations test 17 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{Yd}{n} = \frac{1391}{17} = 81.8$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$\mathbf{Sd^2} = \frac{1066625 - \frac{(1391^2)}{17}}{16} =$$

$$\mathbf{Sd^2} = \frac{1066625 - 113816.5}{16} = \mathbf{59550.5}$$

Test Statistic:

$$\mathbf{t} = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$\mathbf{t} = \frac{81.8 - 0}{\sqrt{\frac{59550.5}{17}}} = \frac{81.8}{59.19} = \mathbf{1.381}$$

With a confidence level of .05 for a two tailed test and 16 degrees of freedom, the level of significance is 2.12. Since $t<2.12$ the test is not significant indicating that the sample wells were not statistically different between 1980 and 1994. Since the two tailed test was not statistically significant no further analysis was necessary to test for direction.

Potter Pond

The following calculations test 17 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{Yd}{n} = \frac{725}{17} = 42.6$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$\mathbf{Sd^2} = \frac{482429 - \frac{(725^2)}{17}}{16} =$$

$$\mathbf{Sd^2} = \frac{482429 - 30919.1}{16} = \mathbf{28219.4}$$

Test Statistic:

$$\mathbf{t} = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$\mathbf{t} = \frac{42.6 - 0}{\sqrt{\frac{28219.4}{17}}} = \frac{42.6}{40.7} = \mathbf{1.0466}$$

With a confidence level of .05 for a two tailed test and 16 degrees of freedom, the level of significance is 2.12. Since t<2.12 the test is not significant indicating that the sample wells were not statistically different between 1980 and 1994. Since the two tailed test was not statistically significant no further analysis was necessary to test for direction.

Cards Pond

The following calculations test 3 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{Yd}{n} = \frac{-73}{3} = -24.3$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$\mathbf{Sd^2} = \frac{45435 - \frac{(-73^2)}{3}}{2} =$$

$$\mathbf{Sd^2} = \frac{45435 - 1776.3}{2} = \mathbf{21829.35}$$

Test Statistic:

$$t = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$t = \frac{24.3 - 0}{\sqrt{\frac{21829.35}{3}}} = \frac{24.3}{85.3} = .28$$

With a confidence level of .05 for a two tailed test and 2 degrees of freedom, the level of significance is 4.303. Since $t<4.303$ the test is not significant indicating that the sample wells were not statistically different between 1980 and 1994. Since the two tailed test was not statistically significant no further analysis was necessary to test for direction.

Trustom Pond

The following calculations test 4 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{Yd}{n} = \frac{397}{4} = 99.3$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$\mathbf{Sd^2} = \frac{107079 - \frac{(397^2)}{4}}{3} =$$

$$\mathbf{Sd^2} = \frac{107079 - 39402.3}{3} = \mathbf{22558.9}$$

Test Statistic:

$$\mathbf{t} = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$\mathbf{t} = \frac{99.3 - 0}{\sqrt{\frac{22558.9}{4}}} = \frac{99.3}{75.1} = \mathbf{1.3}$$

With a confidence level of .05 for a two tailed test and 3 degrees of freedom, the level of significance is 3.182. Since t<3.182 the test is not significant indicating that the sample wells were not statistically different between 1980 and 1994. Since the two tailed test was not statistically significant no further analysis was necessary to test for direction.

Green Hill Pond

The following calculations test 41 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{\text{Yd}}{\text{n}} = \frac{4019}{41} = 98.02$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$\mathbf{Sd^2} = \frac{2052479 - \frac{(4019^2)}{41}}{40} =$$

$$\mathbf{Sd^2} = \frac{2052479 - 393960}{40} = \mathbf{41462.98}$$

Test Statistic:

$$t = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$t = \frac{98.02 - 0}{\sqrt{\frac{42273.6}{41}}} = \frac{98.02}{31.8} = \mathbf{3.1}$$

With a confidence level of .05 for a two tailed test and 40 degrees of freedom, the level of significance is 2.021. Since t>2.021, this test is significant suggesting that nitrogen levels were significantly greater between the two sample years. The one tailed test, with a confidence level of .05 and 40 degrees of freedom, has a level of significance of 1.684, which is also less than the test statistic of 3.1. Therefore, the one tailed test shows that the samples were significantly greater in 1994 (West, Personal Communication, 1996).

Ninigret Pond

The following calculations test 29 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{\mathrm{Yd}}{n} = \frac{538}{29} = 18.6$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$\mathbf{Sd^2} = \frac{661566 - \frac{(538^2)}{29}}{28} =$$

$$\mathbf{Sd^2} = \frac{661566 - 9980.8}{28} = \mathbf{23270.9}$$

Test Statistic:

$$\mathbf{t} = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$t = \frac{18.6 - 0}{\sqrt{\frac{23270.9}{29}}} = \frac{18.6}{28.33} = \mathbf{.66}$$

With a confidence level of .05 for a two tailed test and 28 degrees of freedom, the level of significance is 2.048. Since t<2.048 the test is not significant indicating that the sample wells were not statistically different between 1980 and 1994. Since the two tailed test was not statistically significant no further analysis was necessary to test for direction.

Chapter 6

Interpretation of Results
Empirical Method: Measurement of DIN in Groundwater

The comparison of measured and calculated nitrogen loading estimates in this section tests the accuracy of estimating nitrogen calculations based on literature values, and shows how close the calculated estimates came to the measured samples. The measurements of nitrogen in groundwater were also used to test for significant differences between the 1980 and 1994 sample years.

Average groundwater concentrations of DIN indicate that in five of the six salt pond watersheds as a whole there was a decrease between the two sample years 1980 and 1994. The Paired Student t test for all six pond together indicates that there was a statistically significant decrease between the two sample years. Five out of the six salt pond watersheds show no significant difference in groundwater concentration between 1980 and 1994. In five of the salt ponds with small samples sizes, the variance was so high that there were no statistically significant differences. To be certain the Green Hill data were not skewing the test for the region, the Paired Student t test was run for the region without the Green Hill data. The following calculations test 70 well samples for significant differences in the DIN concentration between the years 1980 and 1992.

$$\mathbf{Yd} = \Sigma\frac{\mathrm{Yd}}{n} = \frac{2978}{70} = 42.54$$

$$\mathbf{Sd^2} = \frac{\Sigma yd^2 - \frac{(\Sigma yd)^2}{n}}{n-1} =$$

$$Sd^2 = \frac{2363134 - \frac{(2878^2)}{70}}{69} =$$

$$Sd^2 = \frac{2363134 - 126692.63}{69} = \mathbf{32412.2}$$

Test Statistic:

$$t = \frac{yd - \mu d0}{\frac{Sd}{\sqrt{n}}} =$$

$$t = \frac{42.54 - 0}{\sqrt{\frac{32412.2}{69}}} = \frac{42.54}{21.67} = \mathbf{1.96}$$

With a confidence level of 0.05 for a two tailed test and 60 degrees of freedom, the level of significance is 2.000. Since $t<2.000$ the test is not significant and the samples do not appear to differ significantly. However, at the 0.10 confidence level for a two tailed test and 60 degrees of freedom, the level of significance is 1.671, (less than the t statistic of 1.96) which suggests significance. The one tailed test, with a confidence level of 0.05 and 60 degrees of freedom, has a level of significance of 1.671, (less than the test statistic of 1.96). Therefore, the one tailed test is significant, and the samples are significantly less in 1994.

The Paired Student t test for the region without Green Hill suggests that the data set is significantly less at the 0.05 confidence level. Assuming we accept the 0.10 confidence level, then the region as a whole did experience a significant decrease in groundwater concentrations of nitrogen between 1980 and 1994.

Over fifteen years, there have been significant decreases in nitrogen in groundwater as measured in the wells. These results apply to the wells, not overall to the coastal loading. Possible reasons for the decrease include dilution from increased rainfall in 1994-95, and the three years preceding. Compared with the calculated budget, there should be some increases in groundwater loading evident from the measured well data in Green Hill pond watershed.

Chapter 7

Nitrogen Loading from Over-land Runoff
Methods and Results

Measurements of over-land runoff in Rhode Island were completed by Nixon et al., (1982) in the SPR and Carter-Hanson (1982) in Providence. Since recent sampling was not available to compare 1980 and 1995, overland runoff from Nixon et al. (1982) and Carter-Hanson (1982) were compared to national models to see if total loading values were similar. Measurements of nitrogen in over-land runoff are available from national research completed under the Nationwide Urban Runoff Program (NURP) (USEPA, 1983), and from local studies undertaken in Rhode Island for the SPR and Narragansett Bay (1982). In order to determine whether runoff estimates for the SPR could be modeled for 1995, NURP averages and New Suburban NURP averages in Washington, D.C. (Schueler, 1987) were compared to data collected in Rhode Island (Nixon et al., 1982; Carter-Hanson, 1982). Each method is based on land-use data from the RIGIS land-use database.

Measurements of nitrogen in overland runoff were reported in the 1982 Statewide Planning Report (Nixon et al., 1982) for residential, urban and agricultural land-uses. Nitrogen concentrations in runoff loading into Narragansett Bay, R.I., from highways, commercial parking, residential and industrial land-uses were completed in 1982 by Carter-Hanson (Carter-Hanson, 1982). The measurements in the NURP were obtained from over 2300 storms monitored at 22 project sites across the nation (EPA, 1983 as cited in Schueler, 1987). Measurements for new suburban NURP sites in Washington, D.C. are from over 300 runoff events monitored during the 1980-81 Washington, D.C. area NURP project (Schueler, 1987).

Statistical analysis of the national NURP project and the Washington D.C. NURP project indicated that there was no significant differences in average pollutant concentrations between the eight widely different urban sites measured, and no consistent correlation between pollutant concentrations and storm volume or intensity (Schueler, 1987). As a result of these findings, both NURP projects support the application of a single concentration value for purposes of estimating pollutant loads from over-land runoff (Schueler, 1987).

Methods and Results

Three different comparisons were made to identify the differences between over-land runoff estimates from Nixon et al. (1982), Carter-Hanson (1982) and Schueler (1987). First, the concentration of nitrogen in runoff from residential and urban land-use was compared; second, the total loading based on these concentrations was calculated for the Point Judith Pond watershed.

Nixon and co-workers (1982), evaluated the nutrient content of storm water runoff from a variety of land-use types in southern Rhode Island. The two land-uses which are of interest to this study are a portion of Main Street, Wakefield, and a parking lot in Wakefield, which are characteristic of an urban setting with high imperviousness and high density development, and the second land-use was a residential section of the Mettatuxet, housing plat along the Narrow River with 1/4 - 1/2 acre housing density. The nitrogen loading calculations from Nixon et al. (1982) were reported in pounds of nitrogen in the runoff per acre of watershed per inch of rain. The calculations for urban and residential land-uses were converted to mg/l in Table 12 in order to compare to nitrogen concentrations from Carter-Hanson and

Schueler in Table 14. These concentrations were then used to calculate the total loading from Point Judith Pond watershed in Table 15.

Table 12. Nixon et al, 1982 Residential and Urban Nitrogen Concentrations in Over-land Runoff Conversion from lb/acre-inch to mg/l.

Residential

$$\frac{.004\text{lb}}{\text{acre-inch}}\text{N} = \frac{.002\text{kg}}{\text{N}} \times \frac{1000000\text{mg}}{1\text{kg}} \times 43560\text{ft}^2 \times \frac{144\text{in}^3}{1\text{ft}^2} \times \frac{.01639\text{ l}}{1\text{in}^3} = \mathbf{0.02\ mg/l}$$

Urban

$$\frac{\dfrac{(.113\text{lb,N})}{\text{acre-inch}} = \dfrac{.051\text{kg}}{\text{N}} \times \dfrac{1000000\text{mg}}{1\text{kg}} = 51256.8\text{mg}}{43560\text{ft}^2 \times \dfrac{144\text{in}^3}{1\text{ft}^2} = 6272640\text{in}^3 \times \dfrac{.01639\text{l}}{1\text{in}^3}} = 102808.6\text{l} = \frac{\mathbf{0.5mg}}{\mathbf{l}}$$

Carter-Hanson completed a preliminary assessment of nutrient loading into Narragansett Bay from urban runoff. This study was undertaken to assess the potential for eutrophication as a natural as well as a man-induced process occurring in the upper portions of Narragansett bay and its watershed (Carter-Hanson, 1982). This author considered two land-uses. The first was a shopping mall parking lot, while the second was a residential area, both in Warwick, R.I. The parking lot was heavily traveled and completely paved with an asphalt-sand mix. Runoff was measured from a 147.32 x 91.44 centimeter elliptical corrugated pipe. The outfall carried runoff from .13 km^2 and represented the total commercial acreage in the upper bay watershed. The residential land-use consisted of single family homes on .10 hectare to .20 hectare lots. A 91.44 centimeter concrete storm drain pipe was measured at the end of Manolla Avenue. The drainage for this watershed was 5.60 km^2, out of a total 176.68 km^2 of residential land-use in the upper Narragansett Bay watershed (Carter-Hanson, 1982). The calculations for urban and residential land-uses were converted to mg/l in Table 13. This was done in an effort to compare nitrogen concentrations estimated by Nixon et al., and Schueler (Table 14). These concentrations were then used to calculate the total loading from Point Judith Pond watershed in Table 15.

Table 13. Carter-Hanson, 1982 Residential and Commercial Land-use. Nitrogen Concentrations in Over-land Runoff Conversion from moles/cm-acre to mg/l.

<u>Residential</u>

\f(2.38moles,cm-acre) x \f(1µm,.000001moles)=2380000µm x 14=33320000mg x

\f(.000001g,1mg) = 33.32g x \f(.001kg,1g) = \f(.03kg,cm-acre) x \f(.3937in,cm) =

$$\frac{\frac{.013kg}{N}}{\text{acre-inch}} \times \frac{1000000mg}{1kg} = \frac{\frac{13118.1mg}{N}}{\text{acre-inch}}, 43560ft^2 \times \frac{144in^3}{1ft^2} = 6272640in^3 \times \frac{.01639l}{1in^3}) =$$

$$102808.6\ l = \frac{\mathbf{0.13\ mg}}{\mathbf{l}}$$

<u>Commercial</u>

.26 moles/cm-acre x 1µm/.000001 moles = 260000µm x 14 =3640000mg x .000001g/1mg = 3.64gx.001kg/1g = .004kg/cm-acre x.3937in/cm = .001 kg/N/acre-inch x 1000000mg/1kg = 1433.1 mg/N/acre-inch)/(43560ft^2 x 144in^3/1ft2 =6272640in^3 x .01639 l/1in^3 = 102808.6 l) = **0.014 mg/l**

Schueler (1987) utilized pollutant concentrations in over-land runoff obtained in the Washington, D.C. area NURP study, and the national NURP data analysis, to calculate over-land runoff from a development site. The difference in land-uses (residential and commercial) is an important consideration as different densities of development result in different areas of imperviousness. Hydraulic factors, such as the percentage of impervious cover and the nature of the drainage system, determine the relative amount of runoff. As impervious surfaces are increased, the cumulative infiltration is sharply reduced (Beaulac and Reckhow, 1982). The actual area of land-use was obtained from the 1988 RIGIS land-use database for each watershed. The RIGIS code used for residential land-use is for <1/4 -1 acre to best match the residential area with the Carter-Hanson model (Carter-Hanson, 1982) and the Metatuxet housing development in Nixon (Nixon, personal communication, 1995). The area loadings for Point Judith Pond watershed are shown in Table 15.

Table 14. Comparison of Nitrogen Concentrations, Nixon et al. (1982), Carter-Hanson (1982) and Schueler (1987).

Runoff Method	**Residential (<1/4 -1 Acre)**	**Commercial (Sale of goods and Services)**
Nixon et al., 1982	0.02 mg/N/l	0.5 mg/N/l
Carter-Hanson, 1982	.013 mg/N/l	0.014 mg/N/l
Schueler, 1987		
Washington, D.C. NURP	.74 mg/N/l	.84 mg/N/l
National NURP	.96 mg/N/l	.96 mg/N/l
	(New Suburban)	(Central Business)

Table 15. Area Loading for Point Judith Pond watershed based on Nixon et al., 1982; Carter-Hanson, 1982; and Schueler, 1987 (National NURP and Washington D.C. NURP)*. Land-use is based on 1988 RIGIS land-use data. 1145 acres are <1.4 -1 acre housing density and 93 acres are commercial land-use (sale of goods and services)*.

Runoff Method	**Residential (1145 acres)**	**Commercial (93 acres)**
Nixon et al., 1982	110.4 kg/yr	225.8 kg/yr
Carter-Hanson, 1982	717.6 kg/yr	6.3 kg/yr
Schueler, 1987		
National NURP	1440 kg/yr	240 kg/yr
Washington D.C.	1111 kg/yr	185 kg/yr
	(New Suburban)	(Central Business)

*Calculations for loading are provided in Appendix G for each of the salt pond watersheds.

Chapter 8

Interpretation of Results
Nitrogen Loading from Over-land Runoff

Considering the data from Table 18, the loading estimates range from 110.4 - 18271.5 for residential land-use, and 6.3 - 1494 kg/yr for commercial land-use. The National NURP model estimates the greatest loading from residential land-use, and the Nixon et al. model estimates the least. National NURP estimates are 166 times the estimate of Nixon et al. (1980). As a measure of comparison to other sources of nitrogen loading in the watershed, the National NURP estimate for over-land runoff from residential land-use is almost as large as the flux from the Saugatucket River (27321 kg/yr). The National NURP loading to Point Judith Pond from over-land runoff is much greater than any other method. The range of loadings from the five possible methods for the same watershed indicates that national averages may over-estimate loading to watersheds, depending on characteristics of the landscape and the area of the watershed being considered. Although the Simple Method has a smaller loading compared to the NURP estimate, the Simple Method is designed for estimating pollutant loads at the site-planning level (Schueler, 1987). Carter-Hanson has a smaller estimate for commercial loading than any other method, perhaps because the loading comes from a parking lot and the area it drains is much smaller (.13 km^2) than the residential (.56 km^2) land-use. Beaulac and Reckhow (1982) suggest that, "As watersheds become increasingly removed from natural undisturbed conditions and undergo increasing human perturbations, the ecological mechanisms controlling nutrient flux become more complex and less well understood." These ecological mechanisms include the effect of reduced amounts of land vegetation which supply and demand nitrogen; the effect of increased impervious surfaces on over-land flow to rivers and streams; and the transport of nutrients and other pollutants in street and roof runoff to drains which empty into rivers and streams (Beaulac and Reckhow, 1982).

One possibility for the increase of nitrogen flux from the Saugatucket River to Point Judith Pond between 1980-81 and 1994-95 is the rate of flow. Over-land runoff may have increased between these time periods due to increases in the fraction of impervious areas within the watershed of the Saugatucket River. Beaulac and Reckhow (1982) also note that hydrologic response is highly dependent on drainage basin characteristics. Different land-uses and changes in land-use over time can have implications for the amount of rainfall in over-land runoff which reaches the streams and the Saugatucket River in the SPR. As the number of housing units and impervious areas increase in the salt pond watersheds, vegetation will be removed, and there will be less opportunity for rainfall infiltration. Changing hydrologic response of the watershed can have a domino effect on the transport of nutrients and other pollutants to both streams, rivers and coastal waters; storm peak discharge will increase, flushing more pollutants; annual runoff will increase and groundwater recharge attenuate; and the days of decreased discharge will increase due to a reduced antecedent moisture conditions (Turner et al., 1977; Ikuse et al., 1975; Okuda, 1975; Yoshino, 1975; Hollis, 1975; Gregory and Walling, 1973; Lindh, 1972; Moore and Morgan, 1969; Holland, 1969; Leopold, 1968; as cited in Beaulac and Reckhow, 1982).

Chapter 9

Discussion

In the SPR, the problem of cumulative impacts is manifested in the past twenty years of management decisions. The biggest nutrient problem is that the salt ponds already have groundwater concentrations of nitrogen one hundred times background levels. Although the 1984 SAMP reduced the potential buildout of the watersheds, zoning amendments applied only to large lots which were not yet platted. Variances for substandard lots which were excluded from the zoning changes allow development of small .10 to .20 hectare lots with traditional ISDS which only remove 10% - 15% of nitrogen. Regulations are not able to directly affect septic systems which are causing the existing problems, unless homeowners decide to change the footprint of their homes, or there is an ISDS failure. Consequently, policy decisions are aimed at future problems: new development, and to some extent, alteration of existing development. The results from the calculated and measured data indicate that some regulatory attempt must be made to address the existing nitrogen sources in addition to the potential. Such regulations would apply to undeveloped lots which are less than .8 hectares. The basis for new regulations which apply specifically to areas with high-density development could be based on existing data which indicate that nitrogen concentrations in groundwater are, in some areas, one hundred times background level in the salt pond watersheds (Olsen and Lee, 1984).

Based on statistical analysis using the paired student t test, there were significant decreases in nitrogen loading in all six salt ponds together. Based on the calculated data, there are several indications which suggest nitrogen is decreasing in quantity in the SPR. Nitrogen loading to groundwater increased in three out of the six salt pond watersheds. Most of the decreases are the results of a decrease in agricultural land-use. However, at buildout, residential land-use could result in increased nitrogen loading to groundwater in all the salt pond watersheds. Although nitrogen loading directly to the surface of all the salt ponds increased due to a higher concentration of nitrogen in atmospheric deposition, and an increase in rainfall, this increase may be the result of different methods used to measure wet atmospheric deposition.

These changes in the nitrogen loading budget are associated with land-use changes. The 1984 SAMP made recommendations to the local town governments to increase the minimum developable lot size to .80 hectares for those lots which were not yet subdivided or platted. Town governments complied with the SAMP recommendations, but there are still many undersized lots platted at less than .80 hectares which are developable through zoning variances, .

The towns look to guidance from the state to regulate sources of pollution, and monitor water quality in the salt ponds, even though the major cause of nutrient loading to groundwater is municipal zoning which continues to permit high density residential development. RIDEM and RICRMC regulations cannot limit the amount of development in the salt pond watersheds based on the impacts of nutrients to groundwater with the present scientific evidence for nutrient loading to the salt ponds. Yet, town planners and coastal resource managers alike agree that high density development and traditional septic system use are the source of eelgrass declines and nuisance algal blooms experienced every summer. Based on the calculated nitrogen concentrations in groundwater, current management efforts[10] to integrate state and local policy will double the amount of nitrogen loading to groundwater at buildout. The basis for this claim is the projected nitrogen concentrations in groundwater in Appendix C. At current zoning and based on nitrogen loading estimates used in this study, Trustom Cards, Green Hill and Potter pond watersheds will either exceed or approach 5 mg/N/l.

Other management decisions which may be impacting the nitrogen loading budget include increased highway construction throughout southern New England, which encourages people to travel by car; emissions from industrial businesses; and state attempts to increase the tourism economy in Rhode Island through advertising and promotional campaigns. In addition to increased nitrogen loading to the salt ponds in 1992, there was a shift in the sources of nitrogen loading to groundwater.

Groundwater Budget

The calculated groundwater loading budget for the salt ponds indicate a shift in the sources of nitrogen loading to groundwater from agriculture to residential land-use. Although fallow fields reduced the loading from agricultural land-uses in 1992, agriculture loading was replaced with loading from residential development in some watersheds. Furthermore, residential sources of nitrogen have the potential to increase groundwater concentrations to 1980-81 levels or greater at buildout in Cards, Point Judith, Potter, Trustom and Green Hill Pond watersheds.

[10]Land-use Act of 1992, Zoning Ordinance Act, Comprehensive Planning Act

Well measurements of nitrate in groundwater by watershed indicate that average concentrations have decreased between the two years 1980 and 1994; and the 1980 and 1994 groundwater samples of nitrogen from private wells in all the ponds are statistically less. The possibility exists that groundwater well measurements may not reflect the annual groundwater concentration of nitrogen entering the salt pond in 1981 or 1994. The hydrology of the region may be having an effect on the groundwater concentrations of nitrogen. The increase in rainfall during the 1994-95 rainfall season may be diluting nitrogen concentrations; whereas, the 1980-81 season was comparatively dry at the time the samples were taken. Since the groundwater hydrology was based on 1980 rainfall, the calculated budget may reflect a wetter year in 1994-95. The calculated budget does not take into account the ability of wetlands to recycle nitrogen by fixation and denitrification. Paerl (1993) notes the functional and quantitative roles watersheds play in the processing of atmospheric deposition are uncertain. Although research by Gold et al., (1990) was based on concentrations of nitrogen in soil-water percolate in the vicinity of the salt pond watersheds, these concentrations may not reflect the ability of other parts of the watershed to incorporate nitrogen. Seitzinger (1988) notes that between 30% and 60% of atmospheric deposition of nitrogen may be lost via denitrification in some watersheds, prior to its discharge into coastal waters. Overall, it is possible that the calculated budget is an over-estimate of actual groundwater concentrations. The Paired Student t Test for **all** six salt pond watersheds indicates measured groundwater concentrations of nitrogen are significantly greater in 1994 then 1980. However, hydrology is a big problem when estimating changes in nitrogen loading; big changes occur over time requiring long sample time and intensive sampling.

Stream Flux

These increases may be associated with the increased rainfall in 1994-95 over 1980-81 (.33 meters more). There was also an increase of the average DIN in the Cross Mills, Teal, and Factory Pond streams.

Atmospheric Deposition

Atmospheric deposition of nitrate-nitrogen (wet) has increased by 0.16 mg/l. Increases in atmospheric deposition are a problem for local and state governments because it means that in order to reduce atmospheric deposition of nitrogen they have to work with regional and/or federal authorities to determine how vehicular traffic and nitrous-oxide emissions from industrial sources can be limited. The 1994-95 atmospheric loading estimates consider both wet and dry deposition (1.04 mg/l). Based on loading from total nitrogen loading, direct atmospheric deposition accounts for between 2% - 21% of the nitrogen loading budgets to the salt ponds in the region. If only wet deposition is compared, there is still an increase of .16 mg/DIN/l. Either the claim by the EPA that nitrous-oxide emissions have been reduced by 25% does not pertain to the southern part of Rhode Island, or the methods used to measure atmospheric deposition in 1980 and 1990 are not comparable. This suggests national averages cannot be relied upon to project atmospheric loading to sensitive coastal water bodies on a local level.

Over-land Runoff

The local and national methods used to determine over-land runoff indicate national averages would grossly overestimate nitrogen loading to the salt ponds. Indeed, all of the methods used to calculate over-land runoff had very different results. One of the basic problems is that each of the methods is generic to the extent that they do not consider the site specific factors of soils, slope, impervious areas etc. for each watershed.

The Nixon et al. (1982) estimates for over-land runoff were part of the nitrogen loading budget for the 1984 SAMP. Storm runoff accounted for less than one percent of the total estimate of inorganic nitrogen inputs to the salt ponds (Olsen and Lee, 1984). Over-land runoff is not a major contributor of nitrogen to groundwater because the salt ponds lie on a glacial outwash plain, underlain by Pleistocene-age glaciofluvial gravel or ground moraine till (Boothroyd, Friedrich, and McGinn, 1985). These characteristics allow rapid infiltration of septic leachate into underlying groundwater and exacerbate the nitrate-nitrogen problems (Boyd, 1993), but do not result in large quantities of overland runoff.

Ninigret and Point Judith Pond watersheds probably contain more impervious areas than the other salt pond watersheds. Based on the research results of Nixon et al. (1982) and Carter-Hanson (1981), Point Judith and Ninigret Pond watersheds have the greatest amount of over-land runoff (Table 15). These pond watersheds contain the most commercial land-uses, and Point Judith Pond, in particular, has a lot of impervious areas around the Saugatucket River, in the Town of Wakefield, R.I., which could contribute over-land runoff.

Salt Pond Habitat

Nitrogen concentrations in the salt ponds are relatively constant with changing nutrient loads from groundwater, atmospheric deposition, and stream flux (Lee, personal communication, 1996). Nitrogen is cycled through the estuarine system by remineralization in the sediments and fixation by plants. Consequently, it is necessary to document changes in habitat as a means of identifying the cumulative impacts of nitrogen loading on the salt pond ecosystem.

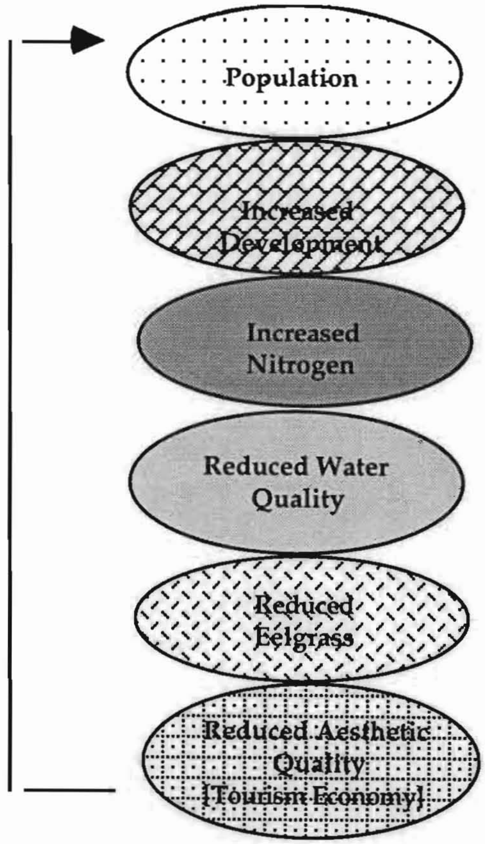
One species of marine vegetation which has important habitat functions in the salt ponds is eelgrass (*Zostera marina*). Eelgrass is a perennial submerged flowering plant with underground stems and erect leafy shoots containing flat leaves up to 1 meter long and ten millimeters wide (Harlin, Thursby and Thorne-Miller, 1988). Various studies show that eelgrass is used as nursery habitat by blue mussels (Mytilus edulis) and bay scallops (Arogpecten irradians) (Heck Jr., et al., 1995). In the salt ponds, eelgrass is used as nursery habitat for winter flounder (Pseudopleuronectes americana) (Saila, 1965). Eelgrass is food for the American brant, Canada geese, black ducks and many other birds (Short et al., 1993). Eelgrass also functions to hold coastal sediments in place, and to filter suspended particles and nutrients from the water (Short et al., 1993). As eelgrass dies and detaches in its annual cycle, it provides a large quantity of organic material which is an important basis of the estuarine food web (Short et al., 1993).

Nutrient induced eelgrass decline is well documented in estuaries and coastal lagoons, including Tampa Bay, Florida (Johansson and Lewis, 1992), the Chesapeake Bay (Orth and Moore, 1983; Dennison et al., 1993; and Kemp et al., 1983), Cockburn Sound, Australia (Cambridge and McComb, 1984), Waquoit Bay, Massachusetts (Costa et al., 1992; Short et al., 1995) and Ninigret Pond in the Rhode Island SPR (Short et al., 1995). However, it is difficult to document the quantity of anthropogenic nitrogen responsible for these declines. Developing a SAV management and restoration policy such as used in the Chesapeake Bay is one possible method of documenting the changes in processes which cause eelgrass decline. Although documenting the health of SAV in the salt ponds might not indicate a cause and effect relationship between the number of houses in a watershed and the area of SAV decline, an SAV management policy might allow RICRMC to use evidence of habitat declines as support for across the board regulations on denitrification, vegetated buffer zones, and decreased fertilizer use. The Chesapeake Executive Council adopted a Chesapeake Bay Submerged Aquatic Vegetation

Policy in order to develop SAV habitat requirements (Batiuk et al., 1992). SAV habitat requirements represent the absolute minimum water quality characteristics necessary to sustain plants in shallow water (Batiuk et al., 1992). Consequently, exceeding any of the characteristics seriously compromises the chances of SAV survival (Batiuk et al., 1992).

A very simple diagram in Figure 6 shows the social, physical and biological relationship of the salt pond community to the ecosystem using eelgrass as a major indicator of health.

Figure 8



Population
Increased Development
Increased Nitrogen
Reduced Water Quality
Reduced Eelgrass
Reduced Aesthetic Quality [Tourism Economy]

Research at the University of Rhode Island Graduate School of Oceanography mesocosms document the impacts of nutrient enrichment on small estuarine systems. In recent experiments, mesocosms enriched with Nitrogen (8200μmole N m^2/day) had phytoplankton blooms which decreased light levels at the sediment surface to below the light saturation levels necessary for eelgrass and Cladophora (Dennison and Alberte, 1982; Hodgkin and Birch, 1982), causing both to decline. In these tanks, both nitrate-nitrogen+ phosphorus and ammonia+phosphorus led to almost the complete demise of eelgrass beds (Taylor, et al., 1995). These enriched mesocosms are similar to loading of highly enriched lagoons such as Moriches Bay (7000 μmole N m^2/day) (Ryther, 1989) and the Childs River and Quashnet River Regions of Waquoit Bay (10000-12000μmoles N m^2/day) (Foreman, personal communication, 1994 as cited in Taylor, Nixon, Granger, Buckley, McMahon, and Lin, 1995).

In the salt ponds, where nitrogen loading is estimated to be 872.24 μmoles m^2/day[11], we are not seeing the complete decline of eelgrass beds (Lee, personal communication, 1995). However, we are beginning to see changes in the eelgrass populations and distribution. The only pond with data on the distribution and population of eelgrass beds over a long time period is Ninigret pond in Charleston, R.I. Eelgrass abundance and distribution were surveyed in 1949 by Wright et al.; 1962 by Brown; 1964 by Conover; 1974 by Short et al.; 1979 and 1980 by Thorne-Miller et al., 1983; and in 1994 by Short and Burdick (in prep). The most recent analysis indicates

[11]Based on the measurements of stream flux and atmospheric deposition, and calculations used in this study.

that aerial distribution of eelgrass beds have declined by 41% over a 32 year period (Short et al., 1995).

Chapter 10

Conclusions

The cumulative impacts of local, state and federal management decisions have resulted in measurable changes in nitrogen loading to the Rhode Island salt ponds. It is possible to identify changes in the source and transmission of nitrogen over a period of time. Managers can use these results to support local and state regulations which limit development in the watersheds of the salt ponds. The following changes in the salt pond watersheds over time illustrate the cumulative impact of past management decisions:

1). Changes in land-use, stream discharge, and atmospheric deposition in the Rhode Island SPR have resulted in decreases of nitrogen loading to the salt ponds.

2). Decreases of nitrogen loading to the salt ponds are the result of management decisions at the local, state and federal level.

3). Nitrogen loading decreases are evident in the calculated budgets for three of the six salt ponds considered, measured groundwater concentrations.

4). Septic systems are the major groundwater source of nitrogen to each of the salt ponds in 1992 assuming only 10% of atmospheric deposition reaches groundwater, and are projected to be a major source when the watersheds are fully developed.

5). Projected increases in nitrogen loading to the salt ponds at total buildout will result in calculated groundwater concentrations in the 4 mg/l to 9 mg/l range.

6). Based on the calculated nitrogen loading budget, nitrogen concentrations in groundwater will continue to increase because of continuing residential development.

7). The differences in the average measured concentrations of nitrate-nitrogen in 1981 and 1994 for the six salt ponds are significantly less.

8). National averages of over-land runoff are an overestimate for watersheds in parts of Rhode Island.

9). Nitrogen is a good indicator of the cumulative impacts of management decisions because changes in the quantity and transmission of nitrogen in the landscape can be quantified.

Chapter 11

Recommendations

Groundwater

Groundwater is the major source of fresh water to the salt ponds (Lee and Olsen, 1985). Consequently, groundwater provides the greatest path of nitrogen transmission to the salt ponds, over atmospheric deposition and stream discharge. In 1980-81, groundwater sources accounted for 70% -100% of the nitrogen entering the salt ponds. 1994-95 groundwater sources accounted for 76% - 98%.

Because groundwater is the major contributor of nitrogen to the salt ponds, it should be the focus of regulations and policies aimed at nitrogen reduction in the salt pond watersheds. Yet, the pattern of stream and atmospheric deposition are indicators that managing groundwater is not adequate to control nitrogen inputs. In as much as individual towns can change their zoning regulations to reduce the potential buildout within their jurisdiction, unless all of the towns commit to zoning changes, only portions of the salt pond watersheds will be managed.

Nitrogen loading from groundwater to the salt ponds should be managed by the SAMP to protect public and private water supplies, and the salt pond ecosystem. The Cape Cod Planning and Economic Development commission (CCPEDC) adopted 5 mg/NO_3-N/l as a standard for planning purposes to protect water supply areas, private wells, small volume community wells and coastal resources (CCPEDC and EPA, 1978). The RICRMC and local communities need to consider the impacts a groundwater concentration of 5 mg/l could have on private wells and the salt ponds. Potter, Cards, and Green Hill pond watersheds will either reach or exceed 5.0 mg/l at buildout based on the calculated nitrogen loading budget.

RICRMC and the local town governments should continue to work together to limit the nitrogen originating from residential development in the salt pond watersheds. Possible cooperative initiatives include:

- Denitrification systems for new development on less than two acre lots (not based on a case by case basis).
- Vegetation buffer zones for new and additional development (not based on a case by case basis).
- Mandatory pump out and septic system maintenance.
- Public funding for new denitrifcation systems and retrofitting of existing septic systems to reduce existing sources of nitrogen.

There are positive efforts being made in the direction of the above mentioned initiatives. RICRMC has a coastal vegetated buffer program, although currently it is implemented on a case by case basis. There is an interagency partnership between RIDEM, RICRMC, and the Department of Administration, Division of Planning for a Coastal Nonpoint Pollution Control Program. Some of the SPR towns are currently considering wastewater management programs. Efforts by the resource agencies and towns need to be moved forward so that nitrogen sources are minimized in the salt pond watersheds. Other cooperative efforts will be necessary to limit nitrogen loading to the salt ponds. The Saugatucket River watershed contributes more than half of the total nitrogen loading to Point Judith Pond. In order to reduce nitrogen loading to Point Judith Pond, the Town of Narragansett is going to have to work with the Town of South Kingstown to identify point-sources of septic discharge and road runoff. Local and state authorities also need to work together in the SPR. The Rhode Island

Department of Environmental Management and RICRMC need to coordinate their efforts to create limits for groundwater concentrations of nitrogen, and document the impacts of current nitrogen loading on salt pond habitat. If RIDEM continues to rely on standards for the siting and design of septic systems, without consideration for the impact of the total number of septic systems in each watershed, then RICRMC control over nitrogen loading to the salt ponds will remain limited to its current jurisdiction.

Chapter 12

Summary

Identifying significant changes in nutrient sources in the salt pond watersheds between 1980 and 1995 illustrates how different management decisions have resulted in increased nutrient loading to the salt ponds. Residential development accounts for the largest portion of nitrogen in the calculated budget for most of the watersheds. Zoning variances and grandfathering of substandard lots, coupled with a lack of recent data to calculate the quantity of nitrogen loading, underestimates the present day loadings and does not accurately represent the changes between 1980 and 1995.

The statistical analysis of groundwater concentrations indicates a significant increase between samples in 1995 and 1980 only in Green Hill pond watershed. The five other salt pond watershed groundwater concentrations do not indicate significant differences. External factors like annual rainfall, water use, changes in vegetation and sample size may be deficiencies in the data. Total nutrient loading values from measured samples and the calculated loading budget are very similar, although the measured loading may not be representative because of the difference in sample sizes in the different watersheds.

Overall, the use of zoning regulations to manage nutrient sources appears to have the greatest impact on nutrient loading changes in the watersheds of the salt ponds. Development has consistently increased since 1980 when the RICRMC recommended a minimum of two acre development within the salt pond watersheds. In some watersheds, development has surpassed what was expected in the 1984 SPR SAMP for full development. Zoning regulations have been an ineffective tool for nutrient source management because of grandfathering, variances and substandard lot development. As a result of an increasing population, increasing number of year round residents, and increasing development, the salt pond communities are going to need creative approaches to limit nutrient loading to the salt ponds beyond zoning regulations. Innovative septic systems or denitrification systems which are already in use in some locations are solutions for any new development, but existing development will continue to be a source of nitrogen to the salt ponds. Policy and regulations for water quality today only focus on future development. Yet five of the six salt ponds in this study already have calculated groundwater concentrations between 2 mg/l and 5 mg/l. Existing development is the source of present water quality problems, yet the solutions being proposed mostly address future limits to nitrogen loading. Open space protection, the continuation of large lot development, retrofitting existing ISDS, and restrictions on fertilizer use are some of the options open to local officials. Increasing the developable lot size is also an option, but will be difficult to support along the south shore where many lots are one acre and smaller, and local planning is beginning to focus on cluster developments (Collins, Personal Communication, 1996).

As officials begin to search for new solutions, coastal managers should look closer at the habitat of the salt ponds, and document the changes occurring from nutrient loading. Developing a closer connection between anthropogenic sources of nitrogen and eelgrass *Zostera Marina* declines should be an integral part of scientific research in the salt ponds.

APPENDICIES

APPENDIX A

Groundwater Loading Worksheets

NITROGEN LOADING TO GROUNDWATER BY SALT POND WATERSHED FROM SEPTIC SYSTEMS (KG/YR)

SALT POND	1981 Septics	1992 Septics	Buildout Septics	1980 People/House	1990 People/House	DIN Load kg/person/yr/septic
POINT JUDITH	1779	2493	3925	3.11	2.98	3.2
POTTER	1362	1376	2662	3.09	2.97	3.2
CARDS	433	475	1403	3.09	2.97	3.2
TRUSTOM	61	133	219	3.09	2.97	3.2
GREEN HILL	1564	2364	3016	3.09	2.97	3.2
NINIGRET	1009	1483	1917	3.89	3.71	3.2

SALT POND	1981 DIN Load kg/yr/septic	1992 DIN Load kg/yr/septic	1981 DIN Load (kg/yr)	1992 DIN Load (kg/yr)	Buildout DIN Load (kg/yr)
POINT JUDITH	9.95	9.54	17705.00	23773.00	37429.00
POTTER	9.89	9.50	13467.00	13078.00	25300.00
CARDS	9.89	9.50	4282.00	4514.00	13334.00
TRUSTOM	9.89	9.50	603.00	1264.00	2081.00
GREEN HILL	9.89	9.50	15465.00	22467.00	28664.00
NINIGRET	12.45	11.87	12560.00	17606.00	22759.00

NITROGEN LOADING TO GROUNDWATER BY SALT POND WATERSHED FROM LAWNS AND GARDENS (KG/YR)

SALT POND	1981 Housing Units	1992 Housing Units	Buildout Housing Units	Lawn/Garden Area (m2)	Lawn/Garden Area (acres)	1981 Total Lawn/ Garden Area (acres)
POINT JUDITH	1779.00	3079.00	4511.00	464.50	0.11	204.19
POTTER	1362.00	1376.00	2662.00	464.50	0.11	156.33
CARDS	433.00	475.00	1403.00	464.50	0.11	49.70
TRUSTOM	61.00	133.00	219.00	464.50	0.11	7.00
GREEN HILL	1564.00	2364.00	3016.00	464.50	0.11	179.51
NINIGRET	1009.00	1483.00	1917.00	464.50	0.11	115.81

SALT POND	1992 Total Lawn/ Garden Area (acres)	Buildout Total Lawn/Garden Area (acres)	DIN Load kg/acre/yr	1981 DIN Load kg/yr	1992 DIN Load kg/yr	Buildout DIN Load kg/yr
POINT JUDITH	353.40	517.76	3.80	775.92	1342.92	1967.50
POTTER	157.93	305.54	3.80	594.04	600.15	1161.05
CARDS	54.52	161.03	3.80	188.86	207.17	611.93
TRUSTOM	15.27	25.14	3.80	26.61	58.01	95.52
GREEN HILL	271.34	346.17	3.80	682.15	1031.07	1315.45
NINIGRET	170.22	220.03	3.80	440.08	646.82	836.11

NITROGEN LOADING TO GROUNDWATER BY SALT POND WATERSHED FROM AGRICULTURE (KG/YR)

SALT POND	Surface Watershed Area (m2)	1981 Agland Area (m2)	1981 Agland Area (acres)	1994 Agland Area (m2)	1994 Agland Area (acres)
POINT JUDITH	14309620	303809	75	22259	6
POTTER	13397870	1323168	327	1323168	40
CARDS	7366817	1709016	422	1709015	120
TRUSTOM	3214443	516343	128	516343	50
GREEN HILL	12300367	373697	92	0	0
NINIGRET	24381988	863000	213	863000	213

SALT POND	1994% of Watershed	Fertilizer Applied kg/N/acre/yr	DIN Load kg/N/acre/yr	1981 DIN Load to Groundwater (kg/yr)	1994 DIN Load to Groundwater (kg/yr)
POINT JUDITH	0	95.50	40.50	3040.38	222.75
POTTER	10	95.50	40.50	13241.67	1620.00
CARDS	23	95.50	40.50	17103.06	4860.00
TRUSTOM	16	95.50	40.50	5167.33	2025.00
GREEN HILL	3	95.50	40.50	3739.79	0
NINIGRET	4	95.50	40.50	8636.51	8636.51

NITROGEN LOADING TO GROUNDWATER BY SALT POND WATERSHED FROM DOMESTIC PETS (KG/YR)

SALT POND	1981 Septics	1992 Septics	Buildout Septics	1980 People/House	1990 People/House
POINT JUDITH	1779	2493	3925	3.11	2.98
POTTER	1362	1376	2662	3.09	2.97
CARDS	433	475	1403	3.09	2.97
TRUSTOM	61	133	219	3.09	2.97
GREEN HILL	1564	2364	3016	3.09	2.97
NINIGRET	1009	1483	1917	3.89	3.71

SALT POND	N Load kg/person/yr	1981 DIN Load kg/yr	1992 DIN Load kg/yr	Buildout DIN Load kg/yr
POINT JUDITH	0.19	1051	1743	2554
POTTER	0.19	800	776	1502
CARDS	0.19	254	268	792
TRUSTOM	0.19	36	75	124
GREEN HILL	0.19	918	1334	1702
NINIGRET	0.19	746	1045	1351

NITROGEN LOADING TO GROUNDWATER BY SALT POND WATERSHED
FROM BASEBALL FIELDS (KG/YR)

SALT POND	Surface Watershed Area (m2)	Surface Watershed Area (acres)	Baseball Fields m2	Baseball Fields ft2	Baseball Fields acres
POINT JUDITH	14309620.00	3535.91	142935.96	1537990.93	35.32
POTTER	13397870.00	3310.61	35733.99	384497.73	8.83
CARDS	7366817.00	1820.34	0.00	0.00	0.00
TRUSTOM	3214443.00	794.29	0.00	0.00	0.00
GREEN HILL	12300367.11	3039.42	0.00	0.00	0.00
NINIGRET	24381988.00	6024.79	35733.98	384497.62	8.83

SALT POND	% of Watershed	Fertilizer Applied kg/ft2/yr	Fertilizer Applied kg/1000ft2/yr	DIN Load kg/acre/yr	DIN Load kg/yr
POINT JUDITH	0.01	1.80	2768.38	3.80	134.21
POTTER	0.00	1.80	692.10	3.80	33.55
CARDS	0.00	1.80	0.00	3.80	0.00
TRUSTOM	0.00	1.80	0.00	3.80	0.00
GREEN HILL	0.00	1.80	0.00	3.80	0.00
NINIGRET	0.00	1.80	692.10	3.80	33.55

NITROGEN LOADING TO GROUNDWATER BY SALT POND WATERSHED FROM MULTI-PLAYING FIELDS (KG/YR)

SALT POND	Surface Watershed Area (m2)	Surface Watershed Area (acres)	Multi-Playing Fields Area (m2)	Multi-Playing Fields Area (ft2)	Multi-Playing Fields Area (acres)
POINT JUDITH	14309620.00	3535.91	30657.20	329871.47	7.58
POTTER	13397870.00	3310.61	7664.30	82467.87	1.89
CARDS	7366817.00	1820.34	0.00	0.00	0.00
TRUSTOM	3214443.00	794.29	0.00	0.00	0.00
GREEN HILL	12300367.11	3039.42	0.00	0.00	0.00
NINIGRET	24381988.00	6024.79	38321.50	412339.34	9.47

SALT POND	% of Watershed	Fertilizer Applied kg/ft2/yr	Fertilizer Applied kg/1000ft2/yr	DIN Load kg/acre/yr	DIN Load kg/yr
POINT JUDITH	0.21	1.80	593.77	3.80	28.79
POTTER	0.06	1.80	148.44	3.80	7.20
CARDS	0.00	1.80	0.00	3.80	0.00
TRUSTOM	0.00	1.80	0.00	3.80	0.00
GREEN HILL	0.00	1.80	0.00	3.80	0.00
NINIGRET	0.16	1.80	742.21	3.80	35.98

NITROGEN LOADING TO GROUNDWATER BY SALT POND WATERSHED FROM UNDEVELOPED LANDS (KG/YR)

SALT POND	Surface Watershed Area (m2)	Open Sapce (m2)	% of Watershed	Buildout Open Space (acres)	Buildout Open Space (m2)
POINT JUDITH	14309620.00	9101562.00	38.40	311.79	1261814.13
POTTER	13397870.00	7392955.00	44.28	187.44	758569.68
CARDS	7366817.00	4732509.00	49.12	1.42	5746.74
TRUSTOM	3214443.00	1492036.00	36.94	262.40	1061932.80
GREEN HILL	12300367.11	6132599.50	42.21	16.14	65318.58
NINIGRET	24381988.00	13318276.20	40.87	891.81	3609155.07

SALT POND	94-95 Mean PPT (m/yr)	80-81 Mean PPT (m/yr)	1994-95 Average DIN in PPT(mg/l)	1980 Average DIN in PPT (mg/l)	94-95 PPT DIN Load (kg/yr)	80-81 PPT DIN Load (kg/yr)
POINT JUDITH	1.15	0.86	1.04	0.49	10885.47	3824.27
POTTER	1.15	0.86	1.04	0.49	8841.97	3106.35
CARDS	1.15	0.86	1.04	0.49	5660.08	1988.49
TRUSTOM	1.15	0.86	1.04	0.49	1784.48	626.92
GREEN HILL	1.15	0.86	1.04	0.49	7334.59	2576.78
NINIGRET	1.15	0.86	1.04	0.49	15928.66	5596.03

SALT POND	80-81 PPT DIN Load (kg/yr)	Buildout PPT DIN Load (kg/yr)	% DIN Loss	94-95 DIN Load Groundwater(kg/yr)	80-81 DIN Load Groundwater (kg/yr)	Buildout DIN Load Groundwater (kg/yr)
POINT JUDITH	3824.27	1509.13	0.10	1088.55	382.43	150.91
POTTER	3106.35	907.25	0.10	884.20	310.63	90.73
CARDS	1988.49	6.87	0.10	566.01	198.85	0.69
TRUSTOM	626.92	1270.07	0.10	178.45	62.69	127.01
GREEN HILL	2576.78	78.12	0.10	733.46	257.68	7.81
NINIGRET	5596.03	4316.55	0.10	1592.87	559.60	431.66

NITROGEN LOADING DIRECTLY TO SALT POND FROM ATMOSPHERIC DEPOSITION (KG/YR)

SALT POND	1980 DIN IN PPT (mg/l)	1991 DIN IN PPT (mg/l)	1980-81 MEAN ANN. RAINFALL (m/yr)
POINT JUDIT	0.49	1.04	0.86
POTTER	0.49	1.04	0.86
CARDS	0.49	1.04	0.86
TRUSTOM	0.49	1.04	0.86
GREEN HILL	0.49	1.04	0.86
NINIGRET	0.49	1.04	0.86

SALT POND	1994-95 MEAN ANN. RAINFALL (m/yr)	POND AREA m2	80-81 PPT VOLUME (m3)	94-95 PPT VOLUME (m3)	80-81 PPT DIN LOAD (kg/yr)	94-95 PPT DIN LOAD (kg/yr)
POINT JUDIT	1.19	6268460.30	5390875.86	7459467.76	2641.53	7757.85
POTTER	1.19	1467790.30	1262299.66	1746670.46	618.53	1816.54
CARDS	1.19	165880.10	142656.89	197397.32	69.90	205.29
TRUSTOM	1.19	745180.80	640855.49	886765.15	314.02	922.24
GREEN HILL	1.19	1701856.10	1463596.25	2025208.76	717.16	2106.22
NINIGRET	1.19	6656582.60	5724661.04	7921333.29	2805.08	8238.19

APPENDIX B

Stream Loading Worksheets

SAUGATUCKET RIVER DISCHARGE AND FLUX, 1994-95		
SAUGATUCKET RIVER	DISCHARGE m3 d-1	FLUX kg d-1
7/27/94	221.29	0.21
10/19/94	17056.44	23.44
11/2/94	14219.28	19.88
11/22/94	64011.38	62.44
12/5/94	156168.00	87.65
2/28/95	323983.26	213.63
4/9/95	118650.42	97.84
4/23/95	87942.35	44.08
5/1/95	232307.46	119.36
5/12/95	123316.34	74.24
5/19/95	139019.6	78.63

FACTORY POND STREAM DISCHARGE AND FLUX, 1994-95		
FACTORY STREAM	DISCHARGE m3 d-1	FLUX kg d-1
7/27/94	1289.78	1.72
10/19/94	2722.16	0.61
11/2/94	2560.70	0.51
11/22/94	4812.51	0.67
12/5/94	14355.51	2.21
2/28/95	9828.50	2.74
4/9/95	8152.75	2.41
4/23/95	6383.53	1.56
5/1/95	11266.00	1.70
5/12/95	9058.61	1.66
5/19/95	5905.66	1.97

TEAL POND STREAM DISCHARGE AND FLUX, 1994-95		
TEAL POND STREAM	DISCHARGE m3 d-1	FLUX kg d-1
7/27/94	4644.29	0.89
10/19/94	7669.83	8.91
11/2/94	9533.8	9.61
11/22/94	4840.23	5.52
12/5/94	11645.85	9.39
2/28/95	16654.87	17.81
4/9/95	7669.99	11.06
4/23/95	9533.8	13.19
5/1/95	3459.7	3.88
5/12/95	2220.75	0.62
5/19/95	1903.99	2.19

CROSS MILLS STREAM DISCHARGE AND FLUX, 1994-95		
CROSS MILLS STREAM	DISCHARGE m3 d-1	FLUX kg d-1
7/27/94	11986.2	0.51
10/19/94	11767.46	2.41
11/2/94	18349.7	3.67
11/22/94	18337.97	4.52
12/5/94	19490.54	5.65
2/28/95	26482.46	5.82
4/9/95	14948.93	2.22
4/23/95	16765.92	1.47
5/1/95	23622.62	1.98
5/12/95	20255.62	2.24
5/19/95	20572.7	4.15

APPENDIX C

Total Groundwater Loading Worksheets
for 1981, 1992 and Buildout

CALCULATED NITROGEN LOADING (kg/yr) TO GROUNDWATER IN THE R.I. SALT POND REGION. 1981, 1992 AND BUILDOUT

SOURCE	GREEN HILL			NINIGRET		
	1981	1992	BUILDOUT	1981	1992	BUILDOUT
GROUNDWATER						
RESIDENTIAL						
SEPTICS ^a	15465	22467	28664	12560	17606	22759
LAWNS ^b	682	1031	1315	440	647	836
PETS ^c	918	1334	1702	746	1045	1351
TOTAL RESIDENTIAL	17065	24832	31681	13746	19298	24946
AGRICULTURE ^d	3740	0	0	8637	8637	8637
UNDEVELOPED LAND ^e	258	733	8	560	1593	432
PLAYING FIELDS ^f						
BASEBALL	34	34	34	67	67	67
MULTI	36	36	36			
TOTAL	21133	25635	31759	23009	29595	34081
DIN Concentration (mg/N/l)	3.1	3.8	4.7	1.5	2	2.3

NITROGEN LOADING ESIMTATES TO GROUNDWATER

Land-use based on 1988 RIGIS database

a - 3.2 kg/N/yr/capita loading and median year-round occupancy based on 1980 and 1990 U.S. Census Bureau data.

b - 3.8 kg/N/acre

c - .19kg/N/person/yr

d - 40.5kg/N/acre. Agriculture at Buildout assumed to be the same as 1992.

e - 10% loss to groundwater from N in precipitation (1980: .49mg/l; 1991:1.04mg/l). Undeveloped Land Loading at buildout decreases because all land zoned for development is assumed to be developed at buildout.

f - Town of South Kingstown and Town of Narragansett fertilizer application rates and areas for multiplaying fields and Nitrate-N loading based on Gold et. al, 1990. Playing Fields at Buildout assumed to be the same as 1992 and 1981.

CALCULATED NITROGEN LOADING (kg/yr) TO GROUNDWATER IN THE R.I. SALT POND REGION. 1981, 1992 AND BUILDOUT.

SOURCE	POINT JUDITH			POTTER		
	1981	1992	BUILDOUT	1981	1992	BUILDOUT
GROUNDWATER RESIDENTIAL						
SEPTICS ^a	17705	23773	37429	13467	13078	25300
LAWNS ^b	776	1342	1968	594	600	1161
PETS ^c	1051	1743	2554	800	776	1502
TOTAL RESIDENTIAL	19532	26858	41951	14861	14454	27963
AGRICULTURE ^d	3040	223	223	13242	1620	1620
UNDEVELOPED LAND ^e	382	1089	151	311	884	91
PLAYING FIELDS ^f						
BASEBALL	134	134	134	34	34	34
MULTI	29	29	29	7	7	7
TOTAL	23118	28332	42487	28454	16999	29715
DIN Concentration (mg/N/l)	0.91	1.1	1.7	5.7	3.4	5

NITROGEN LOADING ESIMTATES TO GROUNDWATER
Land-use based on 1988 RIGIS database
a - 3.2 kg/N/yr/capita loading and median year-round occupancy based on 1980 and 1990 U.S. Census Bureau data.
b - 3.8 kg/N/acre
c - .19kg/N/person/yr
d - 40.5kg/N/acre. Agriculture at Buildout assumed to be the same as 1992.
e - 10% loss to groundwater from N in precipitation (1980: .49mg/l; 1991:1.04mg/l)
Undeveloped Land Loading at buildout decreases because all land zoned for development is assumed to be developed at buildout.
f - Town of South Kingstown and Town of Narragansett fertilizer application rates and areas for multiplaying fields and Nitrate-N loading based on Gold et. al, 1990.
Playing Fields at Buildout assumed to be the same as 1992 and 1981.

CALCULATED NITROGEN LOADING (kg/yr) TO GROUNDWATER IN THE R.I. SALT POND REGION. 1981, 1992 AND BUILDOUT.

SOURCE	CARDS			TRUSTOM		
	1981	1992	BUILDOUT	1981	1992	BUILDOUT
GROUNDWATER						
RESIDENTIAL						
SEPTICS ^a	4282	4514	13334	603	1264	2081
LAWNS ^b	189	207	612	27	58	96
PETS ^c	254	268	792	36	75	124
TOTAL RESIDENTIAL	4725	4989	14738	666	1397	2301
AGRICULTURE ^d	17103	4860	4860	5167	2025	2025
UNDEVELOPED LAND ^e	199	566	1	63	178	127
PLAYING FIELDS ^f						
BASEBALL						
MULTI						
TOTAL	22027	10415	19599	5895	3600	4453
DIN Concentration (mg/N/l)	5.4	3.3	4.1	10.2	4.8	9.1

NITROGEN LOADING ESIMTATES TO GROUNDWATER
Land-use based on 1988 RIGIS database
a - 3.2 kg/N/yr/capita loading and median year-round occupancy based on 1980 and 1990 U.S. Census Bureau data.
b - 3.8 kg/N/acre
c - .19kg/N/person/yr
d - 40.5kg/N/acre. Agriculture at Buildout assumed to be the same as 1992.
e - 10% loss to groundwater from N in precipitation (1980: .49mg/l; 1991:1.04mg/l)
Undeveloped Land Loading at buildout decreases because all land zoned for development is assumed to be developed at buildout.
f - Town of South Kingstown and Town of Narragansett fertilizer application rates and areas for multiplaying fields and Nitrate-N loading based on Gold et. al, 1990.
Playing Fields at Buildout assumed to be the same as 1992 and 1981.

APPENDIX D

Page 163 - USGS Water Table Elevations

SOURCE: U.S. Geological Survey Water Resources Division, Groundwater Levels in Rhode Island.			
1980-81, 1991-92, 1993-94			
WELL WEW 522 1980-81 (Dunn's Corner)		WELL WEW 522 1991-92	
DATE	WATER LEVEL (ft)*	DATE	WATER LEVEL (ft)
10/25/80	14.49	10/26/95	12.24
11/22/80	13.81	11/21/91	12.33
12/27/80	13.44	12/23/91	11.86
1/24/80	13.59	1/24/92	11.74
2/21/81	13.07	2/25/92	11.73
3/28/81	12.45	3/28/92	11.86
4/25/81	12.23	4/28/92	11.78
5/23/81	12.61	5/26/92	12.79
6/27/81	12.55	6/26/92	12.67
7/27/81	13.15	6/24/92	13.21
8/22/81	13.85	8/27/92	12.97
9/26/81	14.14	9/25/92	12.94
AVERAGE	**13.28**	**AVERAGE**	**12.34**
DIFFERENCE			
(80-81) - (93-94):	**0.49**		
WELL CHW18 1980-81		WELL CHW18 1991-92	
DATE	WATER LEVEL (ft)	DATE	WATER LEVEL (ft)
10/25/80	21.13	11/21/91	19.28
11/22/80	21.17	12/23/91	17.23
12/27/81	20.89	1/24/92	17.44
1/24/81	21.21	2/25/92	17.88
2/21/81	20.68	3/28/92	17.44
3/28/81	19.07	4/28/92	17.29
4/25/81	18.97	5/26/92	17.95
5/23/81	18.24	6/26/92	19.01
6/27/81	19.25	6/24/92	19.8
7/27/81	19.45	8/27/92	19.1
8/22/81	20.09	9/25/92	19.12
9/26/81	20.92		
AVERAGE	**20.09**	**AVERAGE**	**18.32**
DIFFERENCE			
(80-81) - (93-94) (feet):	**2.01**		
(80-81) - (93-94) (meters):	**0.61**		
* Feet Below Land Surface Datum			

WELL WEW 522 1992-93		WELL WEW 522 1993-94	
DATE	WATER LEVEL (ft)	DATE	WATER LEVEL (ft)
10/23/92	13.07	10/25/93	14.03
11/27/92	12.26	11/26/93	13.49
12/23/92	10.83	12/28/93	12.07
1/22/93	11.33	1/28/94	12.2
2/19/93	11.39	2/22/94	12.77
3/25/93	10.53	3/24/94	11.12
4/27/93	11.23	4/21/94	11.33
5/25/93	12.21	5/27/94	12.41
6/24/93	13.12	6/27/94	13.09
7/26/93	14.14	7/26/94	13.96
8/26/93	14.65	8/25/94	13.44
9/23/93	14.69	9/28/94	13.56
AVERAGE	**12.45**		**12.79**
WELL CHW18 1992-93		WELL CHW18 1993-94	
DATE	WATER LEVEL (ft)	DATE	WATER LEVEL (ft)
10/23/92	19.12	10/25/93	20.49
11/27/92	19.16	11/26/93	20.56
12/23/92	14.58	12/28/93	18.57
1/22/93	15	1/28/94	17.43
2/19/93	16.1	2/22/94	17.62
3/25/93	13.43	3/24/94	15.08
4/27/93	13.78	4/21/94	14.09
5/25/93	15.85	5/27/94	16.46
6/24/93	17.54	6/27/94	17.89
7/26/93	18.9	7/26/94	18.96
8/26/93	19.83	8/25/94	19.66
9/23/93	20.38	9/28/94	20.16
AVERAGE	**16.97**		**18.08**

APPENDIX E

Page 166 - Well Sample Data
1981 and 1994

W#	POND	NO381	NO394	NH394	DIN94	WD	WA94	WT	USED	SAMPDATE
11	CARDS	158	249.1	1.45	250.55					
15	CARDS	219	73.82	0	73.82	35		ARTESIAN	Y	6/24/94
22	CARDS	342	468.59	0.01	468.6		20	DUG	Y	6/24/94
141	GREENHILL	4	7.43	0.82	8.25	7	44	CASEMENT	N	9/18/94
105	GREENHILL	5	13.18	0.28	13.46	80			Y	8/9/94
29	GREENHILL	13	103.42	0.31	103.73	82	30	DRIVEN	Y	7/9/94
106	GREENHILL	15	28.58	4.17	32.75	80		ARTESIAN	Y	9/3/94
190	GREENHILL	59	51.92	0.01	51.93					7/21/94
45	GREENHILL	62	103.65	0.11	103.76	10	50	DRIVEN	Y	8/22/94
72	GREENHILL	97	190.64	0.44	191.08	20	38	POINT	Y	8/2/94
88	GREENHILL	99	74.81	0.44	75.25	18	38	DUG	Y	7/25/94
102	GREENHILL	111	35.97	0.06	36.03	300	21	DRIVEN	Y	7/24/94
87	GREENHILL	126	176.69	0.33	177.02	12	25	CASEMENT	Y	7/12/94
89	GREENHILL	137	101.23	1.71	102.94	20	20	DRIVEN	Y	7/27/94
150	GREENHILL	154	27.86	79.9	107.76	20	39	CASEMENT	N	9/18/94
147	GREENHILL	156	85.01	0.9	85.91	19	39	CASEMENT	N	9/18/94
145	GREENHILL	172	92.63	1.3	93.93	7	44	CASEMENT	N	9/18/94
85	GREENHILL	200	416.07	0.24	416.31	48	37	ARTESIAN	Y	7/12/94
50	GREENHILL	251	85.88	0.01	85.89		16	POINT	Y	7/24/94
86	GREENHILL	251	192.8	0.47	193.27	10	50	CASEMENT	Y	7/12/94
80	GREENHILL	254	462.37	51.8	514.17	10	57	CASEMENT	Y	7/12/94
81	GREENHILL	263	309.35	0.52	309.87	15	41	DUG	Y	7/27/94
31	GREENHILL	272	391.9	0.24	392.14	21	40	DUG	Y	6/25/94
149	GREENHILL	283	129.6	0.74	130.34	20		CASEMENT	N	9/19/94
79	GREENHILL	302	297.33	35.34	332.67	16	30	DUG	Y	7/25/94
71	GREENHILL	307	268.32	0.14	268.46	20	19	POINT	Y	8/2/94
101	GREENHILL	387	185.69	0.02	185.71	210		DRILLED	Y	8/24/94
94	GREENHILL	436	161.27	0.05	161.32	16	39	DUG	Y	7/25/94
100	GREENHILL	472	354.8	0.47	355.27	82	21	ARTESIAN	Y	8/22/94
98	GREENHILL	480	80.18	0.39	80.57		21	POINT	Y	8/5/94
99	GREENHILL	485	145.89	3.78	149.67	82	44	POINT	Y	7/27/94
97	GREENHILL	498	89.96	0.16	90.12	20	34	DUG	Y	8/5/94
146	GREENHILL	528	102.32	0.99	103.31	8	34	CASEMENT	N	8/24/94
92	GREENHILL	545	405.26	0.52	405.78	10	15	DRIVEN	Y	7/12/94
32	GREENHILL	594	217.22	0.03	217.25	50	16	ARTESIAN	Y	6/25/94
67	GREENHILL	735	291.89	0.49	292.38	15	32	CASEMENT	Y	7/11/94
95	GREENHILL	1098	290.37	0.11	290.48	18	56	DUG	Y	7/25/94
154	NINIGRET	0	0.02	0.25	0.27	125	32	CASEMENY	Y	8/22/94
42	NINIGRET	0	3.74	44.52	48.26	35	50		Y	6/25/94
169	NINIGRET	1	1.62	0.21	1.83	100	80	DRIVEN	Y	7/17/94
28	NINIGRET	1	3.97	0.4	4.37	100	15	DRIVEN	Y	6/25/94
155	NINIGRET	3	12.52	0.45	12.97	125	32	CASEMENT	Y	8/22/94
167	NINIGRET	9	9.44	0.55	9.99	200	30	DRIVEN	Y	9/3/94
170	NINIGRET	16	27.33	0.41	27.74				Y	7/21/94
172	NINIGRET	19	58.44	0.77	59.21	12	75	DUG	Y	7/17/94
133	NINIGRET	22	15.31	0.44	15.75	300	6	DRIVEN	Y	7/19/94
115	NINIGRET	22	46.18	0	46.18	28	18	POINT	Y	7/17/94
168	NINIGRET	22	51.12	0.6	51.72				Y	7/19/94
131	NINIGRET	25	37.03	0	37.03	45	30	DUG	Y	7/17/94
134	NINIGRET	28	23.58	0.02	23.6	15	76	DUG	Y	7/18/94
124	NINIGRET	36	100.9	0.02	100.92	94	20	ARTESIAN	Y	7/17/94

43	NINIGRET	45	86.28	0.1	86.38	40	100	POINT	Y	6/25/94
56	NINIGRET	55	154.3	1.86	156.16	16	14		Y	9/3/94
165	NINIGRET	58	374.39	0.67	375.06				Y	7/19/94
171	NINIGRET	67	13.8	0.08	13.88	120	60	DRIVEN	Y	7/17/94
129	NINIGRET	124	139.35	0.39	139.74	10	28	DUG	Y	8/21/94
117	NINIGRET	124	173.56	0.1	173.66	20	16	POINT	Y	8/22/94
120	NINIGRET	127	183.26	0.03	183.29	350	16	ARTESIAN	Y	8/22/94
123	NINIGRET	128	104.86	0.43	105.29	90	23	ARTESIAN	Y	8/21/94
118	NINIGRET	132	72.26	0.29	72.55	60	24	DRIVEN	Y	7/27/94
130	NINIGRET	150	145.31	0.17	145.48	12	34	DUG	Y	8/5/94
125	NINIGRET	151	160.82	0.06	160.88	14	1	DUG	Y	
174	NINIGRET	151	258.77	0	258.77		12	POINT	Y	7/19/94
159	NINIGRET	154	31.53	0.59	32.12				Y	7/27/94
175	NINIGRET	165	160.39	0.2	160.59	85	17	ARTESIAN	Y	7/19/94
176	NINIGRET	189	330.43	0.08	330.51	20	38	POINT	Y	7/19/94
122	NINIGRET	216	231.15	0.19	231.34	210	34	ARTESIAN	Y	8/21/94
58	NINIGRET	227	220.85	0.28	221.13	10	7	DRIVEN	Y	8/5/94
57	NINIGRET	254	24.49	0.16	24.65	10	50	DRIVEN	Y	8/5/94
25	NINIGRET	290	142.24	0.2	142.44	15	28	DUG	Y	6/24/94
121	NINIGRET	375	367.31	0.3	367.61		16	DRIVEN	Y	8/24/94
127	NINIGRET	412	54.56	0.24	54.8	20	28	POINT	Y	8/21/94
116	NINIGRET	767	236.78	0.64	237.42	20	20	POINT	Y	8/22/94
199	POINTJUDITH	0	0.95	0.06	1.01					7/24/94
2	POINT JUDITH	10	23.33	0.28	23.61			TOWNWATER		6/17/94
65	POINTJUDITH	16	7.44	0.48	7.92		26	DRILLED	Y	8/23/94
63	POINTJUDITH	78	179.19	0.54	179.73	20	44	CASEMENT	N	8/23/94
114	POINTJUDITH	113	96.59	0.01	96.6	75	28	DRIVEN	Y	6/18/94
202	POINTJUDITH	1	0.71	0.49	1.2	400	67		Y	7/24/94
204	POINTJUDITH	9	28.17	0.13	28.3	160	25		Y	7/24/94
180	POINTJUDITH	42	35.17	1.81	36.98	15		CASEMENT	N	8/23/94
157	POINTJUDITH	63	102.76	37.92	140.68	15		CASEMENT	N	9/17/94
203	POINTJUDITH	74	147.23	0.18	147.41	80	25			7/24/94
182	POINTJUDITH	102	69.67	0.25	69.92	15	44	CASEMENT	Y	9/3/94
156	POINTJUDITH	210	235.54	0.97	236.51			CASEMENT	N	9/17/94
185	POINTJUDITH	483	111.43	0.35	111.78					8/21/94
189	POINTJUDITH	579	409.85	0.4	410.25					8/24/94
184	POINTJUDITH	639	699.64	0.51	700.15	25	47	CASEMENT	Y	8/23/94
195	POINTJUDITH	803	640.69	0.83	641.52	14	44	POINT	Y	8/23/94
164	POINTJUDITH	1356	431.8	0.72	432.52	20		CASEMENT		9/17/94
9	POTTER	9	21.42	0.17	21.59			TOWNWATER		
135	POTTER	39	106.83	0.69	107.52	80	15	DRILLED	Y	7/10/94
137	POTTER	41	38.28	0.1	38.38	27	13	DUG	Y	7/7/94
138	POTTER	72	132.85	0.09	132.94	32	85	DRIVEN	Y	7/7/94
197	POTTER	87	11.33	26.32	37.65	20		CASEMENT	N	7/19/94
20	POTTER	136	123.62	0.17	123.79	150	25	DRIVEN	Y	6/24/94
1	POTTER	146	354.96	6.59	361.55			CASEMENT	N	7/8/94
10	POTTER	155	55.6	0.63	56.23	6		CASEMENT	N	7/10/94
136	POTTER	174	68.7	1.13	69.83	45	84	DRILLED	Y	7/9/94
24	POTTER	198	422.97	0.54	423.51	57	26	CASEMENT	Y	
3	POTTER	220	25.64	0.21	25.85			ARTESIAN	Y	6/17/94
6	POTTER	248	10.98	0.43	11.41	15		CASEMENT		
110	POTTER	308	263.84	13.98	277.82	20		CASEMENT	N	9/17/94

14	POTTER	313	371.97	0.68	372.65	35		ROCK CASING	N	9/17/94
5	POTTER	320	22.43	0.14	22.57	25		TOWNWATER		6/17/94
7	POTTER	338	440.28	1.51	441.79	33		CASEMENT	N	9/17/94
4	POTTER	420	26.69	0.15	26.84	25		TOWNWATER		
19	TRUSTOM	1	0.11	26.6	26.71	15	162	DUG	Y	6/24/94
53	TRUSTOM	32	2.22	0.1	2.32	231	44	DRIVEN	Y	7/8/94
17	TRUSTOM	46	3.35	0.08	3.43	26	3	POINT	Y	6/24/94
52	TRUSTOM	642	319.29	0.31	319.6					7/7/94

APPENDIX F

Computation of Yd and Sd^2 for
Paired Student t Test

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd (difference of matched pairs)	Sd^2(difference of matched pairs squared)
CARDS	158	249	-91	8281
CARDS	219	74	145	21025
CARDS	342	469	-127	16129
GREEN HILL	4	7	-3	9
GREEN HILL	5	13	-8	64
GREEN HILL	13	103	-90	8100
GREEN HILL	15	29	-14	196
GREEN HILL	59	52	7	49
GREEN HILL	62	104	-42	1764
GREEN HILL	97	191	-94	8836
GREEN HILL	99	75	24	576
GREEN HILL	111	36	75	5625
GREEN HILL	126	177	-51	2601
GREEN HILL	137	101	36	1296
GREEN HILL	322	28	294	86436
GREEN HILL	156	85	71	5041
GREEN HILL	172	93	79	6241
GREEN HILL	200	416	-216	46656
GREEN HILL	251	86	165	27225
GREEN HILL	251	193	58	3364
GREEN HILL	254	462	-208	43264
GREEN HILL	263	309	-46	2116
GREEN HILL	272	392	-120	14400
GREEN HILL	283	130	153	23409
GREEN HILL	302	297	5	25
GREEN HILL	307	268	39	1521
GREEN HILL	387	186	201	40401
GREEN HILL	436	161	275	75625
GREEN HILL	472	355	117	13689
GREEN HILL	480	80	400	160000
GREEN HILL	485	146	339	114921
GREEN HILL	498	90	408	166464
GREEN HILL	528	102	426	181476
GREEN HILL	545	405	140	19600
GREEN HILL	594	217	377	142129
GREEN HILL	735	292	443	196249
GREEN HILL	1098	290	808	652864
GREEN HILL	0	0	0	0
GREEN HILL	0	4	-4	16
GREEN HILL	1	2	-1	1
GREEN HILL	1	4	-3	9
GREEN HILL	3	13	-10	100
GREEN HILL	9	9	0	0
GREEN HILL	16	27	-11	121
NINIGRET	19	58	-39	1521
NINIGRET	22	15	7	49
NINIGRET	22	46	-24	576
NINIGRET	22	51	-29	841
NINIGRET	25	37	-12	144
NINIGRET	28	24	4	16
NINIGRET	36	101	-65	4225
NINIGRET	45	86	-41	1681
NINIGRET	55	154	-99	9801
NINIGRET	58	374	-316	99856
NINIGRET	67	14	53	2809

NINIGRET	124	139	-15	225
NINIGRET	124	174	-50	2500
NINIGRET	127	183	-56	3136
NINIGRET	128	105	23	529
NINIGRET	132	72	60	3600
NINIGRET	150	145	5	25
NINIGRET	151	161	-10	100
NINIGRET	151	259	-108	11664
NINIGRET	154	32	122	14884
NINIGRET	165	160	5	25
NINIGRET	189	330	-141	19881
NINIGRET	216	231	-15	225
NINIGRET	227	221	6	36
NINIGRET	254	24	230	52900
NINIGRET	290	142	148	21904
NINIGRET	375	367	8	64
NINIGRET	412	55	357	127449
NINIGRET	767	237	530	280900
POINT JUDITH	0	1	-1	1
POINT JUDITH	10	23	-13	169
POINT JUDITH	16	7	9	81
POINT JUDITH	78	179	-101	10201
POINT JUDITH	113	97	16	256
POINT JUDITH	1	1	0	0
POINT JUDITH	9	28	-19	361
POINT JUDITH	42	35	7	49
POINT JUDITH	63	103	-40	1600
POINT JUDITH	74	113	-39	1521
POINT JUDITH	102	70	32	1024
POINT JUDITH	210	236	-26	676
POINT JUDITH	483	111	372	138384
POINT JUDITH	579	410	169	28561
POINT JUDITH	639	700	-61	3721
POINT JUDITH	803	641	162	26244
POINT JUDITH	1356	432	924	853776
POTTER	9	21	-12	144
POTTER	39	107	-68	4624
POTTER	41	38	3	9
POTTER	72	133	-61	3721
POTTER	87	11	76	5776
POTTER	136	124	12	144
POTTER	146	355	-209	43681
POTTER	155	56	99	9801
POTTER	174	69	105	11025
POTTER	198	423	-225	50625
POTTER	220	26	194	37636
POTTER	248	11	237	56169
POTTER	308	264	44	1936
POTTER	313	372	-59	3481
POTTER	320	22	298	88804
POTTER	338	440	-102	10404
POTTER	420	27	393	154449
TRUSTOM	1	0	1	1
TRUSTOM	32	2	30	900
TRUSTOM	46	3	43	1849
TRUSTOM	642	319	323	104329

TOTAL			6997	4415613

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd (difference of matched pairs)	Sd^2 (difference of matched pairs squared)
POINT JUDITH	0	1	-1	1
POINT JUDITH	10	23	-13	169
POINT JUDITH	16	7	9	81
POINT JUDITH	78	179	-101	10201
POINT JUDITH	113	97	16	256
POINT JUDITH	1	1	0	0
POINT JUDITH	9	28	-19	361
POINT JUDITH	42	35	7	49
POINT JUDITH	63	103	-40	1600
POINT JUDITH	74	113	-39	1521
POINT JUDITH	102	70	32	1024
POINT JUDITH	210	236	-26	676
POINT JUDITH	483	111	372	138384
POINT JUDITH	579	410	169	28561
POINT JUDITH	639	700	-61	3721
POINT JUDITH	803	641	162	26244
POINT JUDITH	1356	432	924	853776
TOTAL			1391	1066625

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd (difference of matched pairs)	Sd^2 (difference of matched pairs squared)
POTTER	9	21	-12	144
POTTER	39	107	-68	4624
POTTER	41	38	3	9
POTTER	72	133	-61	3721
POTTER	87	11	76	5776
POTTER	136	124	12	144
POTTER	146	355	-209	43681
POTTER	155	56	99	9801
POTTER	174	69	105	11025
POTTER	198	423	-225	50625
POTTER	220	26	194	37636
POTTER	248	11	237	56169
POTTER	308	264	44	1936
POTTER	313	372	-59	3481
POTTER	320	22	298	88804
POTTER	338	440	-102	10404
POTTER	420	27	393	154449
TOTAL			725	482429

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd	Yd^2
			(difference of matched pairs)	(difference of matched pairs squared)
CARDS	158	249	-91	8281
CARDS	219	74	145	21025
CARDS	342	469	-127	16129
TOTAL			-73	45435

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd (difference of matched pairs)	Sd^2 (difference of matched pairs squared)
TRUSTOM	1	0	1	1
TRUSTOM	32	2	30	900
TRUSTOM	46	3	43	1849
TRUSTOM	642	319	323	104329
TOTAL			397	107079

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd (difference of matched pairs)	Sd^2 (difference of matched pairs squared)
GREEN HILL	4	7	-3	9
GREEN HILL	5	13	-8	64
GREEN HILL	13	103	-90	8100
GREEN HILL	15	29	-14	196
GREEN HILL	59	52	7	49
GREEN HILL	62	104	-42	1764
GREEN HILL	97	191	-94	8836
GREEN HILL	99	75	24	576
GREEN HILL	111	36	75	5625
GREEN HILL	126	177	-51	2601
GREEN HILL	137	101	36	1296
GREEN HILL	322	28	294	86436
GREEN HILL	156	85	71	5041
GREEN HILL	172	93	79	6241
GREEN HILL	200	416	-216	46656
GREEN HILL	251	86	165	27225
GREEN HILL	251	193	58	3364
GREEN HILL	254	462	-208	43264
GREEN HILL	263	309	-46	2116
GREEN HILL	272	392	-120	14400
GREEN HILL	283	130	153	23409
GREEN HILL	302	297	5	25
GREEN HILL	307	268	39	1521
GREEN HILL	387	186	201	40401
GREEN HILL	436	161	275	75625
GREEN HILL	472	355	117	13689
GREEN HILL	480	80	400	160000
GREEN HILL	485	146	339	114921
GREEN HILL	498	90	408	166464
GREEN HILL	528	102	426	181476
GREEN HILL	545	405	140	19600
GREEN HILL	594	217	377	142129
GREEN HILL	735	292	443	196249
GREEN HILL	1098	290	808	652864
GREEN HILL	0	0	0	0
GREEN HILL	0	4	-4	16
GREEN HILL	1	2	-1	1
GREEN HILL	1	4	-3	9
GREEN HILL	3	13	-10	100
GREEN HILL	9	9	0	0
GREEN HILL	16	27	-11	121
TOTAL			4019	2052479

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd (difference of matched pairs)	Sd^2 (difference of matched pairs squared)
NINIGRET	19	58	-39	1521
NINIGRET	22	15	7	49
NINIGRET	22	46	-24	576
NINIGRET	22	51	-29	841
NINIGRET	25	37	-12	144
NINIGRET	28	24	4	16
NINIGRET	36	101	-65	4225
NINIGRET	45	86	-41	1681
NINIGRET	55	154	-99	9801
NINIGRET	58	374	-316	99856
NINIGRET	67	14	53	2809
NINIGRET	124	139	-15	225
NINIGRET	124	174	-50	2500
NINIGRET	127	183	-56	3136
NINIGRET	128	105	23	529
NINIGRET	132	72	60	3600
NINIGRET	150	145	5	25
NINIGRET	151	161	-10	100
NINIGRET	151	259	-108	11664
NINIGRET	154	32	122	14884
NINIGRET	165	160	5	25
NINIGRET	189	330	-141	19881
NINIGRET	216	231	-15	225
NINIGRET	227	221	6	36
NINIGRET	254	24	230	52900
NINIGRET	290	142	148	21904
NINIGRET	375	367	8	64
NINIGRET	412	55	357	127449
NINIGRET	767	237	530	280900
TOTAL			538	661566

NITRATE-NITROGEN (μM)				
WATERSHED	1980	1994	Yd	Sd^2
			(difference of matched pairs)	(difference of matched pairs squared)
CARDS	158	249	-91	8281
CARDS	219	74	145	21025
CARDS	342	469	-127	16129
NINIGRET	19	58	-39	1521
NINIGRET	22	15	7	49
NINIGRET	22	46	-24	576
NINIGRET	22	51	-29	841
NINIGRET	25	37	-12	144
NINIGRET	28	24	4	16
NINIGRET	36	101	-65	4225
NINIGRET	45	86	-41	1681
NINIGRET	55	154	-99	9801
NINIGRET	58	374	-316	99856
NINIGRET	67	14	53	2809
NINIGRET	124	139	-15	225
NINIGRET	124	174	-50	2500
NINIGRET	127	183	-56	3136
NINIGRET	128	105	23	529
NINIGRET	132	72	60	3600
NINIGRET	150	145	5	25
NINIGRET	151	161	-10	100
NINIGRET	151	259	-108	11664
NINIGRET	154	32	122	14884
NINIGRET	165	160	5	25
NINIGRET	189	330	-141	19881
NINIGRET	216	231	-15	225
NINIGRET	227	221	6	36
NINIGRET	254	24	230	52900
NINIGRET	290	142	148	21904
NINIGRET	375	367	8	64
NINIGRET	412	55	357	127449
NINIGRET	767	237	530	280900
POINT JUDITH	0	1	-1	1
POINT JUDITH	10	23	-13	169
POINT JUDITH	16	7	9	81
POINT JUDITH	78	179	-101	10201
POINT JUDITH	113	97	16	256
POINT JUDITH	1	1	0	0
POINT JUDITH	9	28	-19	361
POINT JUDITH	42	35	7	49
POINT JUDITH	63	103	-40	1600
POINT JUDITH	74	113	-39	1521
POINT JUDITH	102	70	32	1024
POINT JUDITH	210	236	-26	676
POINT JUDITH	483	111	372	138384
POINT JUDITH	579	410	169	28561
POINT JUDITH	639	700	-61	3721
POINT JUDITH	803	641	162	26244
POINT JUDITH	1356	432	924	853776
POTTER	9	21	-12	144
POTTER	39	107	-68	4624
POTTER	41	38	3	9
POTTER	72	133	-61	3721
POTTER	87	11	76	5776

POTTER	136	124	12	144
POTTER	146	355	-209	43681
POTTER	155	56	99	9801
POTTER	174	69	105	11025
POTTER	198	423	-225	50625
POTTER	220	26	194	37636
POTTER	248	11	237	56169
POTTER	308	264	44	1936
POTTER	313	372	-59	3481
POTTER	320	22	298	88804
POTTER	338	440	-102	10404
POTTER	420	27	393	154449
TRUSTOM	1	0	1	1
TRUSTOM	32	2	30	900
TRUSTOM	46	3	43	1849
TRUSTOM	642	319	323	104329
TOTAL			2978	2363134

APPENDIX G

Runoff Method	Residential (acres)	N Concentration (mg/l)	Total Loading (kg/yr)	Commercial (acres)	N Concentration (mg/l)	Total Loading (kg/yr)
Nixon						
Point Judith	1145	0.02	110.28	93	0.5	223.94
Potter	795	0.02	76.57	25	0.5	60.20
Cards	343	0.02	33.04	13	0.5	31.30
Trustom	70	0.02	6.74	0	0.5	0.00
Green Hill	1438	0.02	138.51	20	0.5	48.16
Ninigret	2045	0.02	196.97	95	0.5	228.76
Carter-Hanson						
Point Judith	1145	0.013	71.69	93	0.014	6.27
Potter	795	0.013	49.77	25	0.014	1.69
Cards	343	0.013	21.47	13	0.014	0.88
Trustom	70	0.013	4.38	0	0.014	0.00
Green Hill	1438	0.013	90.03	20	0.014	1.35
Ninigret	2045	0.013	128.03	95	0.014	6.41
Schueler						
National NURP						
Point Judith	1145	0.96	5293.67	93	0.96	429.97
Potter	795	0.96	3675.52	25	0.96	115.58
Cards	343	0.96	1585.79	13	0.96	60.10
Trustom	70	0.96	323.63	0	0.96	0.00
Green Hill	1438	0.96	6648.30	20	0.96	92.47
Ninigret	2045	0.96	9454.63	95	0.96	439.21
Schueler						
Washington NURP						
Point Judith	1145	0.74	4080.54	93	0.84	376.22
Potter	795	0.74	2833.21	25	0.84	101.13
Cards	343	0.74	1222.38	13	0.84	52.59
Trustom	70	0.74	249.47	0	0.84	0.00
Green Hill	1438	0.74	5124.73	20	0.84	80.91
Ninigret	2045	0.74	7287.95	95	0.84	384.31

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